A GEO-INFORMATION BASED MODEL FOR ASSESSING AND MONITORING FOREST FIRE RISK IN THE STATE OF MISSOURI, UNITED STATES OF AMERICA

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DOCTOR OF PHILOSOPHY

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A GEO-INFORMATION BASED MODEL FOR ASSESSING AND MONITORING FOREST FIRE RISK IN THE STATE OF MISSOURI, UNITED STATES OF AMERICA

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ABSTRACT

Despite the fact that a lot of resources has been invested in fire protection and suppression, the number of fires recurring in Missouri in recent decades has continued to markedly increase. Much of forest research has focused on the biological and physical aspects of fire with comparatively less attention given to the importance of socio-economic variables and risk assessment. There is therefore the need to develop a framework for the assessment and monitoring of forest fire risk which is presently lacking in the state of Missouri. This is where this study derives its relevance. Missouri is currently ranked among the top seven states ravaged by wildfires in the United States. The specific objectives are to apply a geoinformation based model for the assessment of wildfire risk in Missouri; assess social vulnerability to wildfire, analyze the relationship between climate variability and wildfires; and examine wildfire policy in the United States, and the implications for wildfire risk reduction in Missouri. Forest risk and vulnerability assessment of Missouri was undertaken using some measurable environmental parameters influencing forest fire risk and vulnerability. Using the four ecological zones in Missouri and geospatial model as the basis of analysis, three forest risk zones were identified. These are high forest fire risk zones, moderate forest fire risk zone and low forest fire risk zone. Also, social vulnerability to wildfire risk in Missouri was assessed with the American Community Survey data on social and demographic variables for the state of Missouri and social vulnerability index (S_0VI). The study divided Missouri into five geopolitical zones from which ten counties were randomly selected for this study. The selected counties formed the basis on which fourteen social and demographic indicators were identified and assessed using Bogardi, Birkmann and Cadona conceptual framework. The result of the analysis shows that S_0VI estimated for the five geopolitical zones of Missouri is moderate with a rating scale of 1.42 – 1.71. Education, income and marital status have a rating scale of 2.0 - 3.0 attributed for the high value of Social Vulnerability to wildfire. Race / ethnicity, language spoken, employment and percentage of house units that are mobile homes had a low S_0VI value of 1.0 thereby contributing positively to resilience to wildfire risk. The relationship between climate variability and wildfire occurrence in Missouri was analyzed by examining the correlation between wildfire seasonality frequency, acres burned, and temperature from 1995 to 2018 using Pearson correlation method. The results reveal no significant correlation between climate and wildfire occurrence in Missouri. However, the study observes that other factors such as arson arising from human activities could have contributed to wildfire occurrence in Missouri. Finally, the study examines the failure of wildfire mitigation policy framework in the state, and how this has impacted wildfire mitigation efforts in the state of Missouri. The study concludes that though government involvement in wildfire risk reduction is quite impressive, there is no policy framework at the local and state level towards combating wildfire hazards. This becomes necessary because wildfire in Missouri is human induced caused majorly by arson. The current social and demographic characteristics of forest landowners, land use change, wildland-urban-interface, ecological and climate change are critical factors that must be put into consideration in formulating effective and sustainable wildfire policy reduction initiatives in Missouri.

APPROVAL PAGE

The faculty below, appointed by the Dean of the School of Graduate Studies, have examined a dissertation titled "A Geo-Information Based Model for Assessing and Monitoring of Forest Fire Risk in State of Missouri, United States", presented by Omolola V. Akinola, candidate for the Doctor of Philosophy degree, and certify that in their opinion, it is worthy of acceptance.

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DEDICATION

This research is dedicated to the Almighty God. May HIS name be praised forever.

CHAPTER 1

1.0 INTRODUCTION

1.1 Introduction

Forest fires are one of the causes of ecological disturbance in the climate ecosystems of the world. Fire has long been considered as a natural phenomenon, largely incorporated in Missouri climate systems, having shaped their diversity function and their distribution and evolution (Rundel, 1981).

Even though a lot of resources have been invested in fire prevention and suppression, the number of fires recurring in Missouri in the recent decades has continued to markedly increase. Much of forest fire research has focused on the biological and physical aspects of fire with comparatively less attention given to the importance of socioeconomic variables and risk assessment especially identifying pattern of human population most at risk and the factors that help explain performance of mitigation that can help reduce that risk. There is also the need to develop a geospatial framework for the forest fires assessment which is presently lacking in Missouri State. This study therefore attempts at developing a geoinformation based model for assessing and monitoring the risk of forest fires in Missouri State. The choice of Missouri is influenced by the fact that it ranks among the top five states ravaged by wildfires (National Interagency Fire Center (NIFC), 2015).

Forests are Missouri greatest renewable resource; Missouri is home to at least 730 species of wildlife. The state of Missouri boasts more than 14 million acres of forest land. It ranks seventh out of the 20 Northeastern states in the amount of forested acreage. Only New York, Michigan, Maine, Pennsylvania, Minnesota, and Wisconsin have more forest land. Harvesting and processing trees into wood products gives thousands of people jobs and contributes $3 billion each year to Missouri's economy (Missouri Department of Conservation, 2016).

In the last 13 years, wildland fires burned an average of 24,209 acres per year and prescribed fires burned an average of 38,078 acres per year (NIFC, 2015). Forest fires are still are still a major threat to Missouri's forest. While most forest fires in Missouri are accidents and preventable, a full 40 percent of forest fires that happen every year are deliberately set. Arson accounts for at least one out of every three forest fires every year.

1.2 Statement of Research Problem

Forest and wildfire are considered as a disaster that distresses terrestrial environments and causes economic destruction for people, such as missing income relative to the land use, destruction and loss of property, damages to the agriculture and loss of biodiversity, (Adab, Kanniah, & Solaimani, 2013; Malik, Rabbani, & Faruq, 2013). Also, it is one of the most important parts of land degradation that is caused by deforestation and desertification (Malik et al., 2013). Information on the risk assessment of forest fire zones is essential for the effective and sound decision-making process in the forest management (Verde & Zêzere, 2010). Forest fire risk evaluation is therefore a critical part and in fact the most important step in forest fire management because knowing where the risk is highest is essential to minimize threats to life, property, and natural resources.

In Missouri, wild land fires in the last 13years have burned an average of 24,209 acres per year, and prescribed fires burned an average of 38,078 acres per year (National Interagency Fire Centre, 2015). While most forest fires in Missouri are accidents and preventable, a full 40 percent of forest fires that happen every year are deliberately set. Arson accounts for at least one out of every three forest fires every year (Missouri Department of

Conservation, 2016). Despite the fact that forests are Missouri greatest renewable resources and a home to at least 730 species of wildlife and also covered more than 14 million acres of forest land, the number of fires recurring in Missouri in recent decade has continued to increase. There is therefore the need to reduce the large-scale losses arising from forest fire.

Most of the forest fire researches have focused on the biological and physical aspects of fire with comparatively less attention given to socio- economic variables and risk assessment especially the pattern of human population most at risk. There is also the need to produce a forest fire risk map as well as apply a geoinformation based model for forest fire risk assessment and monitoring which is presently lacking for Missouri State. This study therefore applies a geospatial based model for assessing and monitoring the risk of forest fires in Missouri. The choice of Missouri is influenced by the fact that it ranks among the top five states in the United States of America ravaged by wildfires (National Interagency Fire Centre, 2015). A growing body of research focuses on the identification of residential populations most likely to be affected by future wildfire events and the steps they can take to alleviate the risk on the their private property (Collins, 2009; Gaither, Goodrick, Murphy, & Poudyal, 2015; Haas, Calkin, & Thompson, 2014)). This research is a response to increasing private property damages and other disruptions to human populations from wildfires, including destruction of homes, numbers of individuals evacuated, damage to public infrastructure, and modification to local revenue due to fluctuations in local economic activity. Reducing forest fire risk and losses to private residents are a central policy concern in wildfire management (Gude, Jones, Rasker, & Greenwood, 2013) and by implication Missouri State.

Better characterizing the human population most exposed to or at risk from wildfires and exploring the relationships between potential losses and mitigation actions, can provide useful insights for ongoing debates about forest fire management. It is expected that this study will be of help to produce a map of forest fire vulnerability useful for land use planning, emergency management personnel, and policy makers to better understand the factors influencing increased forest fire risk and determine the mitigation strategies or planning efforts that residents are most likely to perform.

1.3 Research Questions

i. What is the appropriate method of mapping forest fire risk in Missouri?

ii. What are the climatic variables that contribute to making Missouri environment fire prone?

iii. To what extent can the capabilities of remote sensing and geographic information system (GIS) techniques be exploited in the assessment and monitoring of forest fire risk and production of forest fire risk map?

iv. What is the best social vulnerability model to assess and identify social vulnerability of Missouri residents to Wildfire?

v. What are utilitarian values of such a forest fire risk map for the State of Missouri? All these forms the research questions this study seeks to address

Answers to these questions are reflected all over this dissertation. From the objectives, which identifies the major milestones of this study, to the methodology, which identifies how the questions will be answered.

1.4 Aim and Objectives of Study

The aim of this study is to develop a geoinformation based model for assessing and monitoring the risk of forest fires in Missouri State, United States of America. To realize this aim, specific objectives are to:

i. apply a geoinformation based model for the assessment of wildfire risk in Missouri.
ii. assess the social vulnerability to wildfire risk in the study area.
iii. examine the relationship between climate variability and wildfire occurrence.
iv. examine wildfire policy in the United State, and the implication for wildfire risk reduction in Missouri.

CHAPTER 2

2.0 ASSESSMENT OF FOREST FIRE VULNERABILITY ZONES IN MISSOURI, UNITED STATES OF AMERICA

2.1 Introduction

Wildfire or forest fire is considered a disaster that distresses the terrestrial environment resulting in loss of biodiversity and causes economic destruction including, destruction and loss of property and damage to agriculture (Merlo & Rojas Briales, 2000; Westerling, Gershunov, Brown, Cayan, & Dettinger, 2003; Malik, Rabbani, & Faruq 2013; Adab et al., 2013; Verde & Zezere, 2010). Also, it is one of the major causes of land degradation which exacerbates deforestation and desertification (Malik et al., 2013). Information on the distribution of forest fire zones is essential for the effective and sound management of forests (Verde & Zezere, 2010). Forest fire risk evaluation is therefore a critical part, and in fact, the most important step in forest fire management because knowledge of the relative risk of specific locations is essential to minimizing threats to life, property, and natural resources.

In Missouri, wildfires in the last 13 years have burned an average of 24,209 acres per year, while prescribed fires burned an average of 38,078 acres per year (National Interagency Fire Center, 2015). While most forest fires in Missouri are due to accidents and preventable, about 40 percent of forest fires that happen every year are deliberately set. Arson accounts for at least one out of every three forest fires every year (Missouri Department of Conservation, 2016). Forests are Missouri's greatest renewable resource and home to at least 730 species of wildlife with more than 14 million acres of forest land. The number of fires occurring in Missouri in recent decades has continued to increase with devastating consequences for the affected areas. Not surprisingly, Missouri is among the top five states in the United States of America ravaged by wildfires (National Interagency Fire Center, 2015).

Despite the frequency of forest fires in Missouri, only a few studies exist in the literature. These include the studies by Brosofske, Cleland & Saunders, (2007), which examined the factors influencing modern fire occurrence in the Mark Twain National Forest, Missouri, and Yang, He, & Shifley, (2008) that analyzed the spatial controls of occurrence and spread of wildfires in the Missouri Ozark Highlands and other few studies. There is therefore the need to develop a forest risk assessment framework for forest management in the state. This study employs a hazard model to assess and evaluate the risk of forest fires in Missouri. The resulting index should aid forest planners in defining areas of greatest risk and support proactive actions to minimize the risk posed by forest fires.

2.1.1 The Study Area: State of Missouri.

Missouri's geology, geography, and location at the boundaries of several ecological regions have combined to create a unique mix of ecosystems. Two major references are used in the literature for Missouri's ecological classification. These are "The Terrestrial Natural Communities of Missouri" (Nelson, 2005), and Missouri's ecological classification system (ECS), modeled after the United State Forest Service (Nigh and Schroeder, 2002). The Terrestrial Natural Communities of Missouri classified 85 district communities in Missouri, including 33 forest and woodland communities.

The ECS on the other hand divides Missouri State into four distinct ecological sections (see Figure 3), and this helps to explain why Missouri has such high levels of species diversity. Each ecological section has unique geologic history, soils, topography, and weather patterns that have resulted in unique assemblages of plants and animals. The four ecological sections are:

i. The Central Dissected Till Plains
ii. Osage Plains
iii. Ozark Highlands, and
iv. Mississippi Alluvial Plain.

The Central Dissected Till Plains includes most of northern Missouri. Soils are mainly comprised of glacial till deposited over 400,000 years ago. Much of the landscape consisted of prairies, especially in the upland. Forest and woodlands make up a relatively small component of the landscape (varying from 5 to 15 percent of the land cover).

The Osage Plains is located in west-central Missouri and consist of unglaciated soils. This zone is dominated by prairies and extensive wetland complexes. Currently, agriculture is very dominant. In fact, more than 60 percent of this zone is used for pasture. Forest and woodlands are currently limited and are found mostly on steeper slopes and valleys.

The Ozark Highlands zone is Missouri's most heavily forested and this makes up most of the south half of the state. The Ozark Highlands, stretching from southern Missouri across northern Arkansas and containing small portions of Illinois, Kansas, and Oklahoma, is essentially a plateau that has undergone weathering for up to a quarter billion year (McNab & Avers, 1994). This process has resulted in a highly diverse landscape containing more than 200 endemic species in the Ozark Highlands section (Foti & Bukenhofer, 1998). The highest and least rugged parts of Ozarks tend to be flat to gently rolling plains that were formerly covered with prairies, savannas, and open woodlands. These hills historically supported oak and oak-pine woodlands and forest with countless springs, cave, fens, cliffs, and glades scattered throughout. Much of the area is covered with forest and woodland cover, though it has been impacted significantly by harvesting practices, livestock grazing and altered fire regimes.

The Mississippi Alluvial Basin is found in Missouri's extreme southeast area and consists mostly of alluvial soils with the primary exception of Crowley's Ridge, a named hill region that rises above the Mississippi River alluvial plain. Historically, most of this section was poorly drained and consisted of marshes, swamps, and bottomland forests. In the twentieth century, most of the bottomlands were drained and converted to cropland. It should be stated that within each ecological section, Missouri is further divided into 31 subsections, delineated using the same criteria of climate, geomorphology, topography, soils, and potential vegetation types. The study therefore assesses forest fire risk of the four ecological sections discussed above.

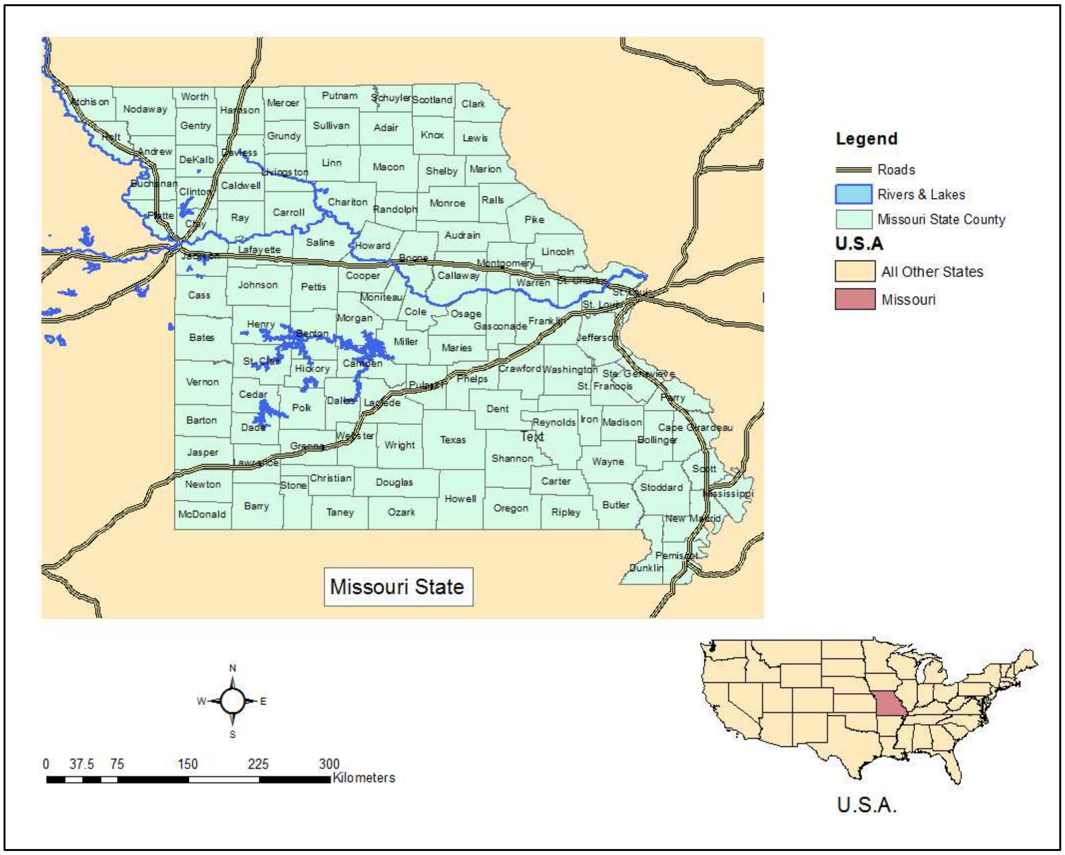

Figure 1: Study area showing roads and rivers and location of Missouri state in USA

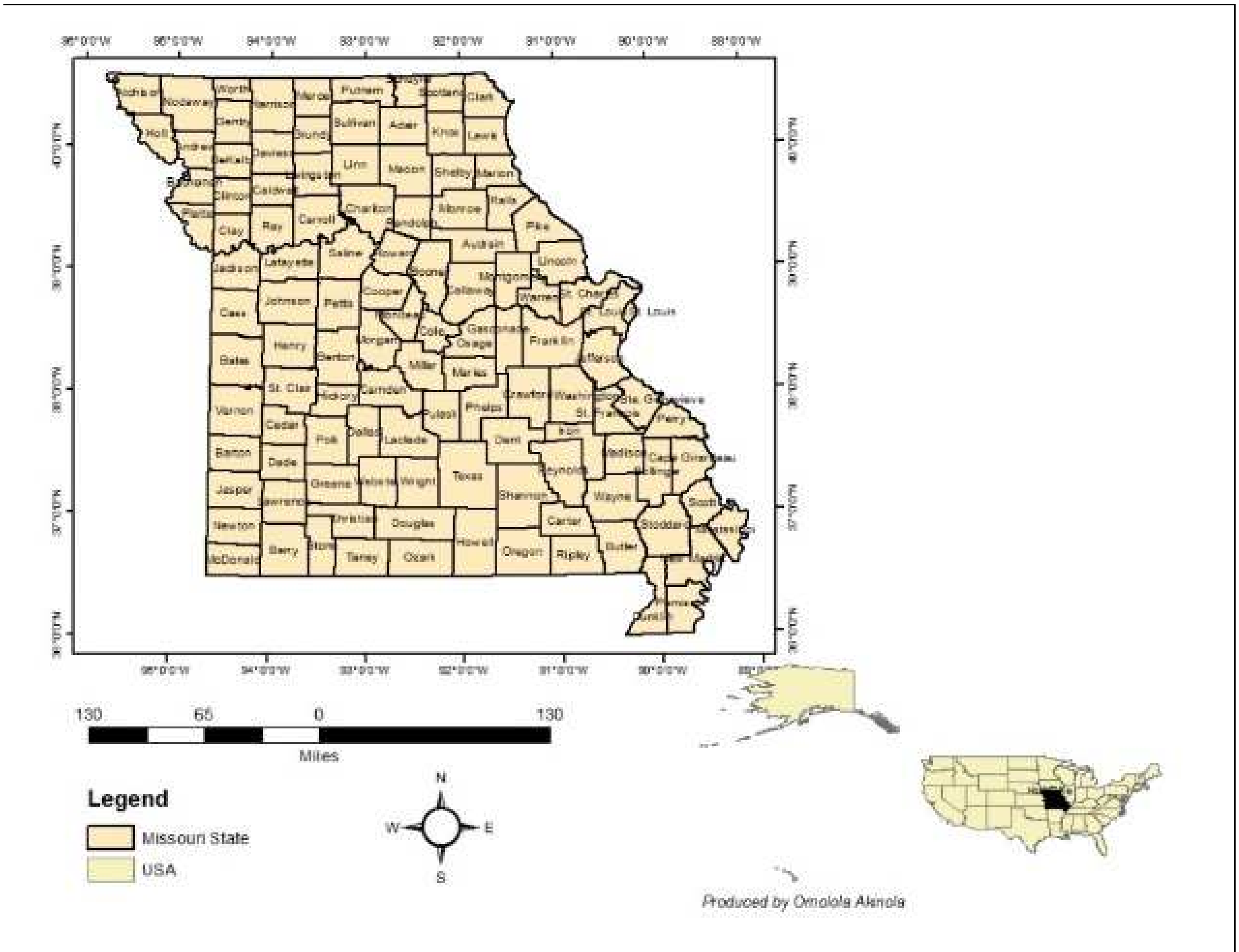

Figure 2: Study area showing Missouri counties and location of Missouri state in USA

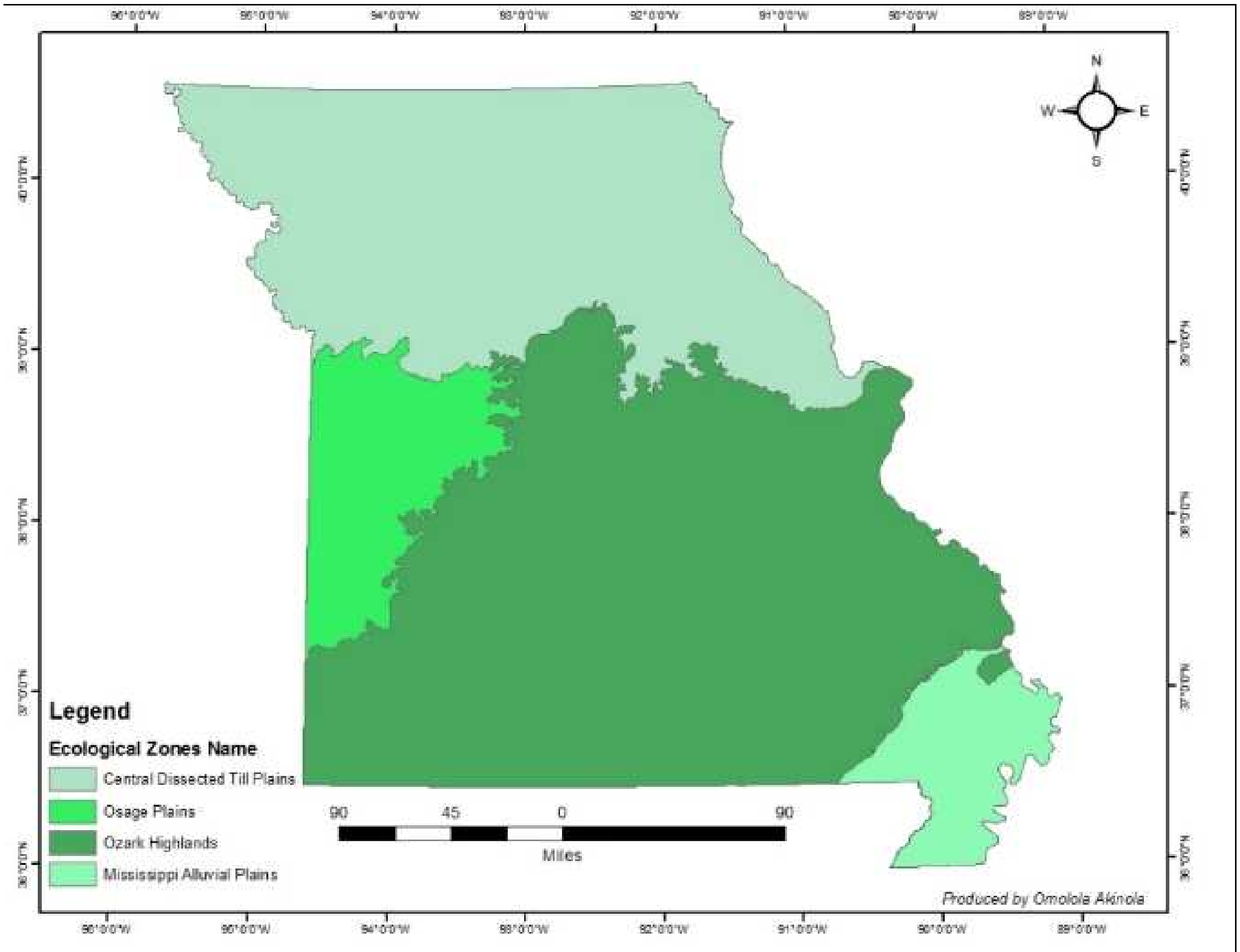

Figure 3: Study area showing Missouri ecological zones

2.2 Methods and Data

Secondary data were used for this study. These include the vegetation maps of Missouri such as vegetation types and vegetation density, housing density and type of forest ownership. These were collected from the publications of US forest service on Missouri's forest in 2008. Data on relief and proximity of forest to the nearest settlement were collected from the thematic maps prepared by the Department of Conservation in Missouri.

2.2.1 Clipping Processes

The map of ecological zones of Missouri was prepared from USA ecological zones shapefile downloaded from the United States Department of Agriculture (USDA) Forest Service website. The shapefile was loaded into ArcMap 10.5 where Clip tool in Geoprocessing Menu was used to extract and display only the study area.

2.2.2 Exporting from Excel

Forest or Wildfire records data acquired from Missouri Department of Conservation and converted from Excel Workbook (*.xlsx) format to comma delimited (.*csv) in order to obtain files com ArcGIS. Reformatting of some of the data and/or the field headers was done in ArcGIS so they can be readily imported and displayed in ArcGIS.

2.2.3 Forest Fire Risk Model

A situation of risk is due to incompatibility between hazard and vulnerability levels on the same plot. This decomposition of risk into two components is a first step in the simplification or conceptualization of a complex reality, which should allow for a better comprehension and analysis of the problem (Giland & Givone, 1997; Ologunorisa, 2004).

In Figure 4, the first factor hazard, depends on the forest type, forest density, frequency of forest fire, length of time it takes to burn while the second factor is called vulnerability and represents the sensitivity of land use to forest fire. Consequently, it depends on the type of land use and the social perception of risk. Vulnerability can vary across space, even for the same type of land use and can also evolve in time (Ologunorisa, 2004).

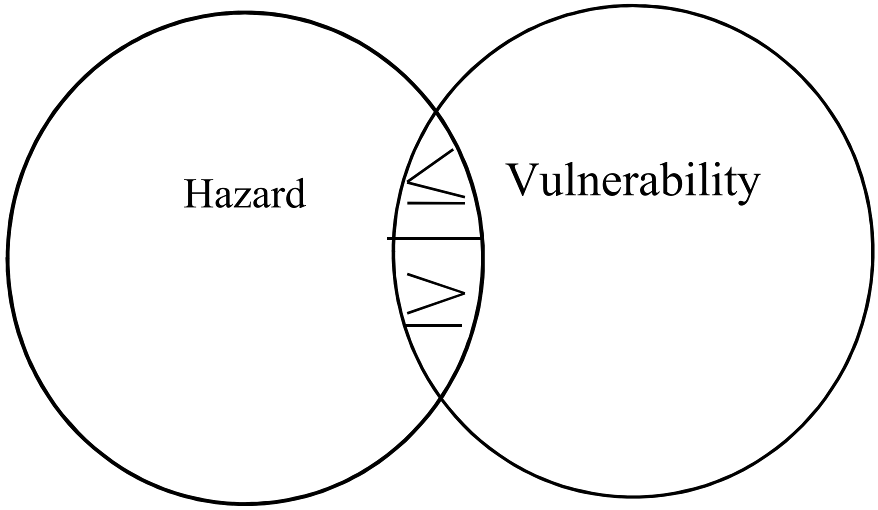

Figure 4: Risk conceptualization (Source: Giland & Givone, 1997)

2.2.4 Prediction of Risk

The risk of forest fire of a particular area depends on hazard factors and vulnerability factors. A method of assessing risk from a natural disaster is given by the risk index, as follows:

$$Risk\ Index\ (RI) = HF \times VF \ \ldots\ldots\ldots(1)$$

Where HF = Hazard factors, the hazard factors are defined as the elements that cause the risk and, in this case, the environmental characteristics of forest fire such as forest type, density, frequency of forest fire, forest fire level of damage, forest fire duration, burnt area while the vulnerability factors are defined as the land use and social economic variables or socioeconomic perception of risk. And this includes types of land use, proximity to fire source, length of time forest fire was experienced, adequacy of fire preventive measures, the extent of property damage, and type of ownership and housing density. The hazard factors are calculated using the equation (2)

$$HF = f\,(H_1 \times H_2 \times H_3 \times H_4 \times H_5 \times \ldots\ldots\ldots H_n) \ldots\ldots\ldots\ldots\ (2)$$

While Vulnerability factors are calculated using the equation (3)

$$VF = f\,(V_1 \times V_2 \times V_3 \times V_4 \times V_5 \times V_6 \times \ldots\ldots V_n)\,)\ldots\ldots\ldots\ (3)$$

Finally, the forest fire risk index is calculated by Equation (1). In this method, the higher the value of the forest fire risk index, the higher the degree of risk.

2.2.5 Forest Fire Vulnerability Assessment in Missouri

The forest fire risk map of Missouri was prepared based on the forest fire risk assessment of some environmental parameters in four ecological zones used in this study. The forest fire vulnerability assessment was achieved in two stages.

The first step involves the identification of the most important environmental/biophysical parameters (i.e., hazard and vulnerability indices) influencing forest fire. Eight indices were utilized for measuring levels of forest fire risk in the study area, as shown in Table 1. Their selection is based on the reasoning that they are capable of truly measuring forest fire risk because previous studies have shown that they have a strong positive bearing on forest fire generating and vulnerability components of forest fire hazard. Also, the parameters selected are easy to measure and quantify with clear potential for bringing out internal variations within the study area.

The second stage involves the quantitative rating and assessment of the environmental parameters (hazard and vulnerability factors) in the selected ecological zones for forest fire risk mapping based on the rating scales devised in this study. The scales for scoring the environmental parameters in this study are shown in Table 1. In devising the scales for scoring the eight environmental parameters, emphasis was placed on the range of values obtained from topographical/relief map, vegetation map, forest types, forest density and housing density map of the study area. The rating procedure adopted was based on Clarke's principle

(Clarke, 1951). This entails multiplying the scores of the parameters selected in this study in each ecological zone to give the Missouri forest fire risk index for land use planning. By multiplying the scores, the forest fire risk in each ecological zone will be limited to the least favorable parameter influencing forest fire (that is the law of minimum). This is preferred to the additive method of computing indices, which assumed that the different parameters add together without interference (Gbadegesin & Nwagwu, 1990; Ologunorisa, 2004). In this method, the higher the value of the risk index, the higher the degree of vulnerability.

Table 1: Environmental parameters selected for defining forest fire vulnerability zones in Missouri

S/N	Parameters	Range of Values	Scores
1	Forest Types	Built up urban areas and horticultural trees and shrubs	1
		Native grassland and native shrubs	2
		Native forest and woodlands	3
2	Forest density	0 – 14 percent	1
		15 – 49 percent	2
		≥ 50 percent	3
3	Perceived extent of forest damage	≤ 25 percent	1
		26 – 50 percent	2
		≥ 50 percent	3
4	Perceived adequacy of forest fire control measures in percentage	≥ 50 percent	1
		25 – 50 percent	2
		≤ 25 percent	3
5	Housing density per km2	0 – 16	1
		16 – 28	2
		≥ 28	3
6	Types of forest ownership	State and Local forest service	1
		Federal ownership	2
		Private ownership	3
7	Relief	≤ 400 feet	1
		400-800 feet	2
		≥ 800 feet	3
8	Proximity to settlement	≥ 1000 meters	1
		500 – 1000	2
		≤ 500 meters	3

2.3 Results and Discussion

Based on the rating scale in Table 1, three Forest fire risk classes were obtained and shown in Table 3, while Table 2 shows the computation of the forest fire risk indices for the data collection in the selected ecological zones used in the study. The forest fire risk classes obtained in Table 3 were used to divide the state of Missouri into forest fire vulnerability zones for land use planning as shown in Figure 5. Table 2 was used to generate Table 3. Central Dissected Plains and Osage Plains were merged in ArcMap as moderate risk zone since the two ecological zones have the same forest fire risk index value. The resulting forest fire risk map consisting of three zones is shown in Figure 5. The first zone consists of areas of high forest fire risk, and these are counties in Ozark Highland areas. The second zone is made up of moderate forest risk. These include the counties in the central Dissected Till Plains and the Osage Plains. The counties in the Mississippi Alluvial Basin located in the southeast corner constitute the zone with lowest forest fire risk among the three zones.

Infact, the Ozark highlands with high percentage of forest coverage have also been identified by previous researchers as having the highest occurrence of forest fire in Missouri (Brosofske et al., 2007; Yang et al., 2008).

Table 2: Computation of forest fire vulnerability indices in Missouri

S/No	Ecological zone	Forest Type	Forest Density	Freq. of Forest fire	Ext. of Forest Damage	Adeq. of Forest fire	Housing Density	Ownership of Forest	Prox. of Settlement	Relief	Forest Risk index	Forest Risk Class
1.	**Central Dissected Plains**	2	2	2	2	2	3	1	3	1	288	II
2.	**Osage Plains**	3	2	2	2	2	1	3	2	1	288	II
3.	**Ozarks Highland**	3	2	2	2	2	2	3	3	3	2713	III
4.	**Mississippi Alluvial Plains**	1	1	1	1	2	3	3	2	1	36	I

Table 3: Forest fire risk class for landuse planning

Forest Fire Risk indices	Forest Fire Risk Class	Remark
≤ 500	I	Low forest fire risk zone
500 – 1500	II	Moderate forest fire risk zone
≥ 1500	III	High forest fire risk zone

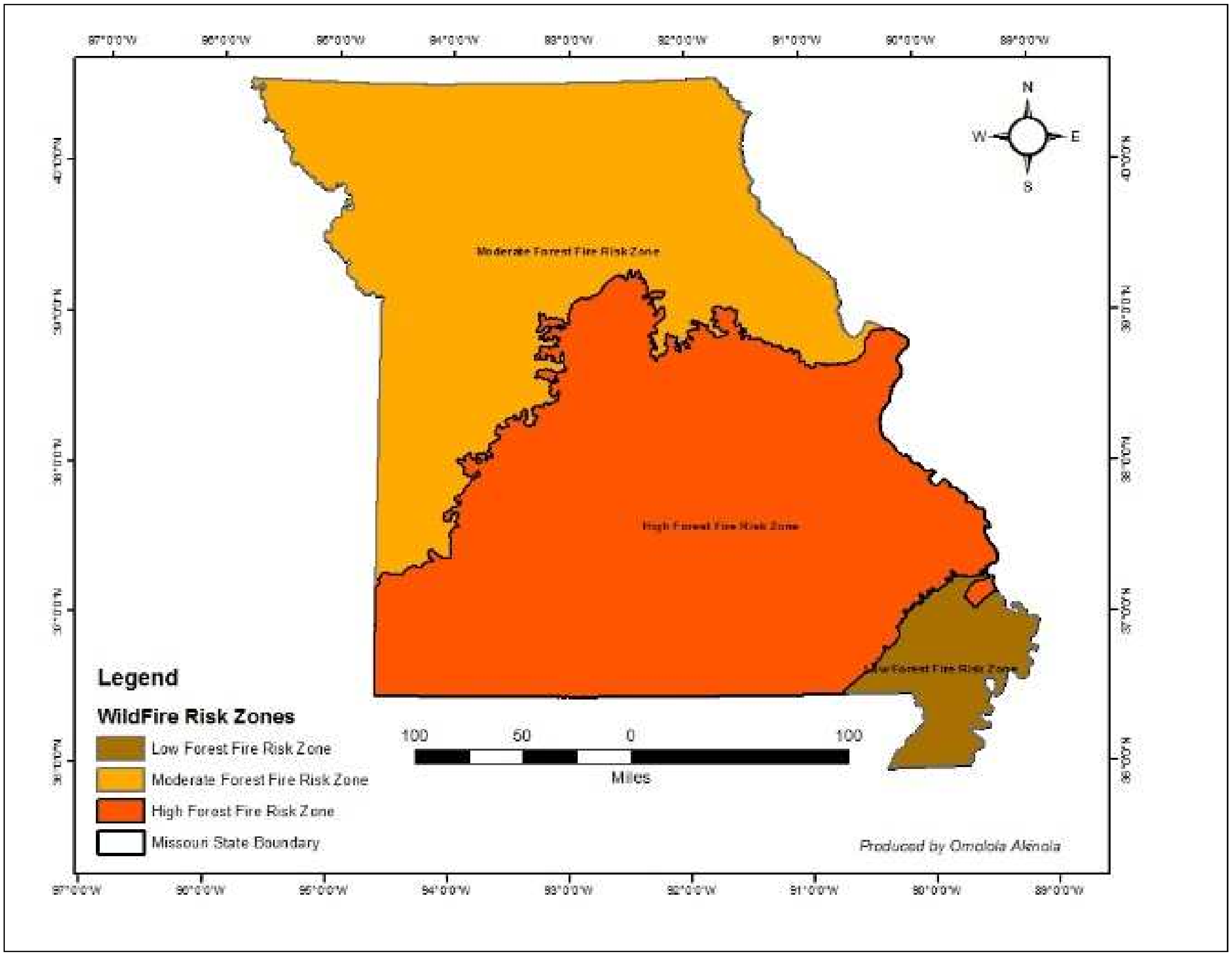

Figure 5: Forest fire risk map

2.3.1 Cluster and Hotspot Analysis (Anselin Local Moran's I)

This analysis was carried to determine clustering of reported fire occurrences. Pattern analysis determines if clustering is high in fire records data as shown in Figure 6. Cluster/Outlier Analysis (Anselin Local Moran's I) tool was used to perform pattern analysis and display the result to highlight the degree of clustering in Figure 7. The tool was used to calculate the LMiIndex which indicate whether the feature has other features of similar values near it; LMiZScore, LMiPValue and the COType field that distinguishes between a statistically significant (0.05 level) cluster of high values (HH), cluster of low values (LL), outlier high value surrounded primarily by low values (HL) and outlier low values surrounded primarily by high values (LH).

The result of the hotspot analysis reveals the location of high hotspots. The red symbols show where high values are clustered with other high values. The green symbols on the legend which are not evident on the map indicate areas with low values of clusters. The yellow symbols show locations where high and low values are clustered.

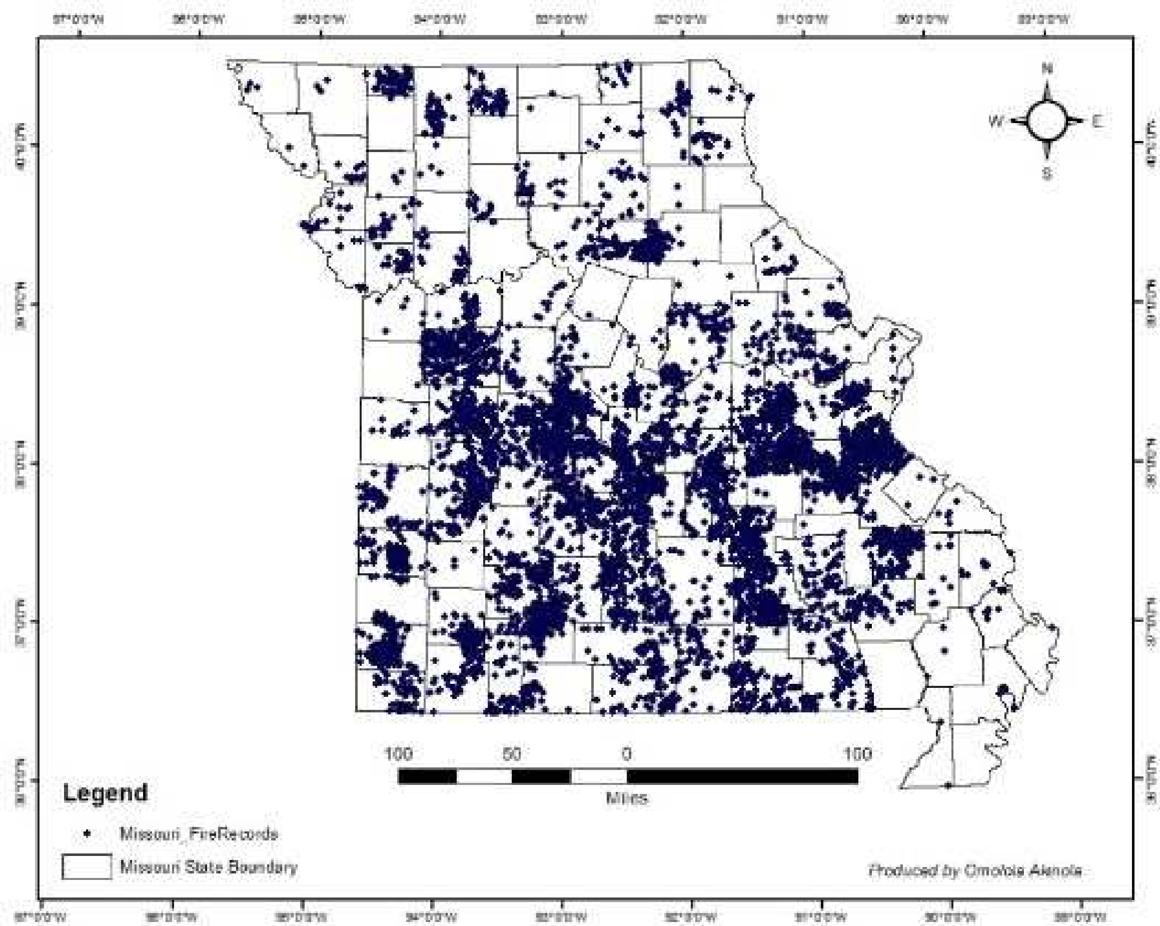

Figure 6: Map showing fire records

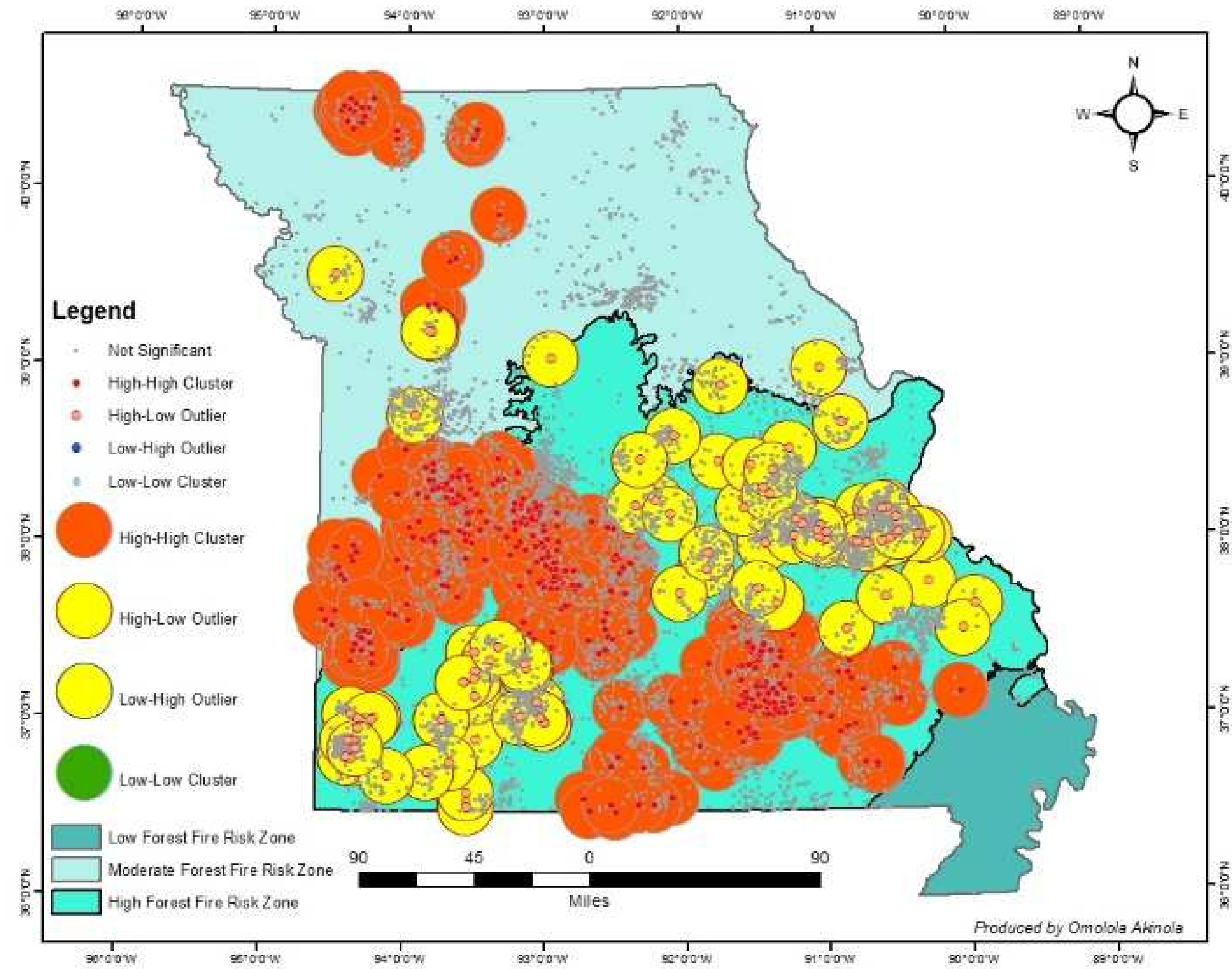

Figure 7: Cluster/Pattern and hotspot map

2.4 Conclusion

The study successfully applied a risk index developed based on forest fire hazard and vulnerability factors for the assessment of forest fire vulnerability zones in Missouri, United States. This risk index is based on parameters such as topographical/ relief map, vegetation map, forest types, forest density and housing density map. An assessment of the forest fire vulnerability zone for forest resource management on a predetermined set of eight criteria delineated the State of Missouri into three forest fire risk zones: high forest fire risk, moderate forest fire risk and low forest fire risk zones. Based on the above findings, we conclude that it would be helpful to intensify efforts on forest fire control management strategies in zones II and III since forest fire hazard and vulnerability factors are higher in these areas.

CHAPTER 3

3.0 ASSESSMENT OF SOCIAL VULNERABILITY TO WILDFIRE IN MISSOURI, UNITED STATES OF AMERICA

3.1 **Introduction**

Studies on wildfire becomes necessary to reduce property damages, destruction of homes, displacement of human population, and loss of local revenue (Paveglio, Prato, Edgeley & Nalle, 2016). Forests are Missouri greatest renewable resources; Missouri is home to at least 730 species of wildlife. The state boasts more than 14 million acres of forest land (Missouri Department of Conservation, 2008). It ranks seventh out of the 20 Northern east states in the amount of forested acreage. Only New York, Michigan, Maine, Pennsylvania, Minnesota, and Wisconsin have more forest land. In the last 13 years, wildland fires burned an average of 24,209 acres per year and prescribed fires burned an average of 38,078 acres per year (NIFC, 2015). Forest fires are still a major threat to Missouri's forest. While most forest fires in Missouri are accidents and preventable, a full 40 percent of forest fires occur every year (Missouri Department of Conservation, 2016).

Despite the enormous resources that have been invested in fire prevention and suppression, the number of fires recurring in Missouri in the recent decades has continued to markedly increase. Much of forest fire research has focused on the biological and physical aspects of fire with comparatively less attention given to the importance of socioeconomic variables and risk assessment especially identifying pattern of human population most at risk and the factors that help explain performance of mitigation that can help reduce that risk.

Apart from the work of Akinola and Adegoke (2019) which assessed forest fire vulnerability zones in Missouri; Brosofske et al., (2007) on factors influencing modern wildlife occurrence in the Mark Twain National Forest of Missouri and Yang et al., (2008) on spatial controls of occurrence and speed of wildfires in Missouri Ozark highlands, little or nothing exist in the literature on social vulnerability assessment to forest/wildfire in Missouri State. This is a crucial step towards developing a wildfire a policy for reducing wildfire risk and losses in the study area. This is where this study derives its relevance. The aim of this study therefore was to assess and identify social vulnerability of Missouri residents to wildfire risk.

3.1.1 Conceptual Framework

Vulnerability refers to the capacity of society and individuals exposed to a natural hazard, to be harmed, resist, cope with, or recover from impact (Dwyer, Zoppou, Nielsen, Day & Roberts, 2004; Wisner et al., 2004; Cutter & Finch, 2008). At present, there is no consensus on the definition of vulnerability, and therefore no single accepted method of assessing vulnerability in the literature. Despite this, there is still a fair amount of consensus in the literature that there exist three main types of vulnerability. These are biophysical vulnerability, social vulnerability, and a combination of the two (Ge, Liu, Li, & Shi, 2008; Ge, Dou, & Gu, 2013).

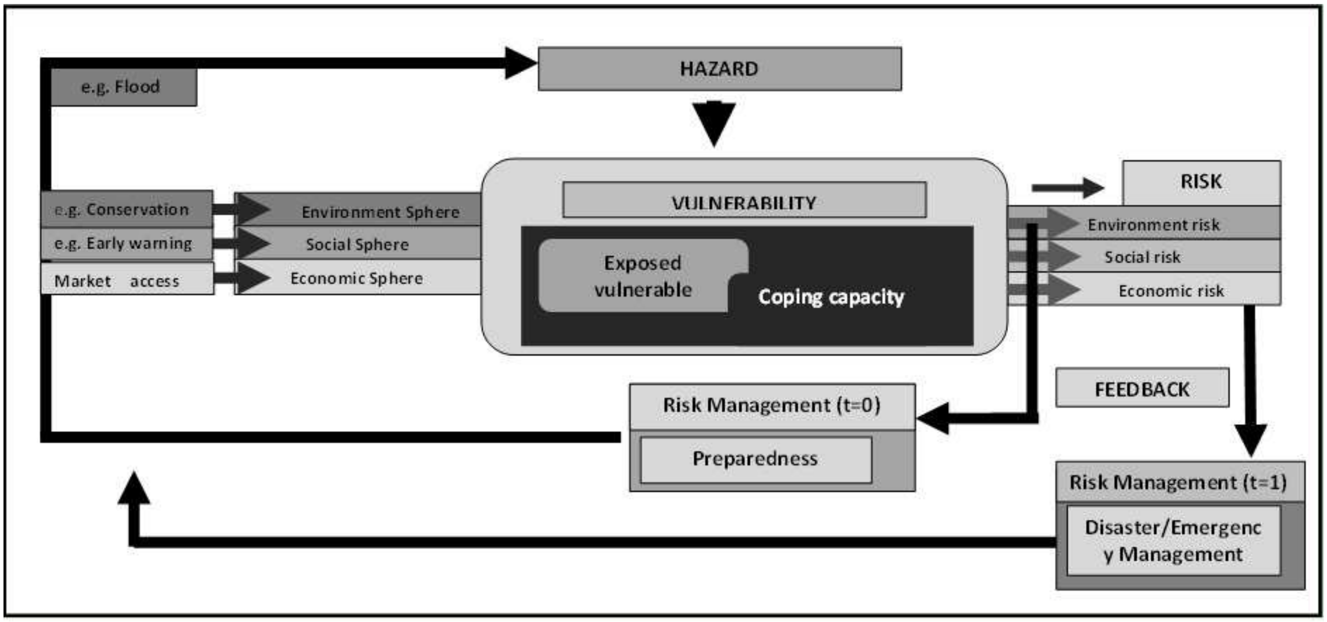

Figure 8: Conceptual framework for vulnerability
Source*:* Bogardi & Birkmann (2004); Cardona (1999, 2004)

In the past few decades, five major conceptual models have been proposed. These are: the risk-hazard (RH) model by Burton, Kate, & White, 1978; the pressure and release (PAR) model (Blaikie, Cannon, Davis, & Wisner, 1994); the hazard of place (HOP) model (Cutter, 1996); Turner and colleagues vulnerability framework (Turner et al*.,* 2003); and the Bogardi – Birkmann – Cardona (BBC) model (Birkmann, 2006), have proposed for understanding social vulnerability. These conceptual models in vulnerability literature laid a sound theoretical basis for the analysis and assessment of social vulnerability.

This research adopts the Bogardi – Birkmann – Cardona (BBC) model (see Figure 8) because it allows us to examine the three components of vulnerability. These are exposure, susceptibility, and adaptive/capacity to wildfire in the study area. The framework also combines hazard and vulnerability in a risk reduction perspective. The concept was used to identify variables and interpret results.

3.1.2 Factors Affecting Social Vulnerability

The variables that influence social vulnerability which are always cited in the literature are listed in Table 4. The generally acceptable ones are age, gender, race, and socio-economic status. Others include disability factor, non – English speaking immigrants, the homeless, transients and seasoned tourists. The quality of human settlements (such as housing type and construction, infrastructure, and lifelines) and the built environment are important variables in understanding social vulnerability.

These characteristics influence potential economic losses, injuries, and fatalities from natural hazards.

3.2 Methodology

The study used the American Community Survey data for the state of Missouri from 2012-2016 and social vulnerability index (S_0VI). Demographic data and socio-economic characteristics of Missouri residents were extracted from the published American Community Survey 2012-2016 data on Missouri. The scale of study is at sub regional level of Missouri. The state of Missouri was divided into geopolitical zones as defined by the government of Missouri. These are South west Missouri, Southeast Missouri, Central Missouri, Northwest Missouri and Northeast Missouri. Ten counties were randomly selected for study in each geopolitical zone to obtain the composite value for each zone.

Identification of variables and interpretation of results in this study were based on the BBC framework by Bogardi, Birkmann and Cardona (see Figure 8). The term “BBC” framework comes from the conceptual model developed by Bogardi and Birkmann (2004) and Cardona (1999, 2001). The assessment of vulnerability was based on fourteen variables identified in Table 4. These variables were selected based on a priori theory and knowledge from the literature. This approach is referred to as deductive approach for selecting social vulnerability indicators.

The indicators for the estimation of the level of vulnerability were based on the following rating scale: (0 – 1.0) low vulnerability; (1.1 – 2.0) moderate vulnerability; and (2.1 – 3.0) high vulnerability (see Table 5). Equal weights were assigned to indicators to calculate S_0VI. It has been argued by Cutter, Boruff, & Shirley, (2003) and Muyambo, Jordaan, & Bahta, (2017) that there is no theoretical basis for assigning different weights to indicate different levels of significance to individual factors' contribution to social vulnerability. The indices were then summed up and divided by the total number of indicators to obtain the SoVI for the five geopolitical zones of Missouri State (see Table 6).

The SoVI was calculated using the following mathematical equation:

$$V^{soc} = \sum_{i=n}^{12} = W_i^{soc} V_i^{soc}$$

$$\mathrm{V}^{\mathrm{soc}}\ f(\ W_1^{soc}V_1^{soc} + \ W_2^{soc}V_2^{soc} + \ W_3^{soc}V_3^{soc} + - - - W_{12}^{soc}V_{12}^{soc} \qquad (1)$$

Where: $V_1^{soc} = age$, $V_2^{soc} =$ marital status, $V_3^{soc} = Income$, V_4^{soc}=education;

V_5^{soc}=race/ethnicity; V_6^{soc}= employment; V_7^{soc}= language spoken; V_8^{soc}= persons in households; V_9^{soc}= ; V_{10}^{soc}=length of stay in residence; V_{11}^{soc}= disability; V_{12}^{soc}= age of structures.

W_1^{soc}= equal weighting factor for all variables.

Table 4: Selected social vulnerable indicators

	Indication (Variable)	Measure	Relationship with Vulnerability
1	Age	>65yrs. <18yrs. More old and under age	Higher vulnerability
2	Marital status	Married, Single or Separated	Single/separated-high Vulnerability
3	Income	Annual income earned	Low income- high Vulnerability
4	Education	Level of education	More education-low Vulnerability
5	Race/Ethnicity	Percentage of white to non-whites	More whites- less Vulnerability
6	Employment Status	Percentage of unemployment adults	High rate of Unemployment- high Vulnerability
7	Language spoken	Percentage that speaks in English	More population that speaks English – low Vulnerability
8	Person in households	Percentage of householders, spouse and children	Few persons – low Vulnerability
9	Length of stay in residence	Percentage of residents who stayed less than 5years	The more the years – low Vulnerability
10	Disability	Percentage of disabled in population	Larger number of disabled – high Vulnerability
11	Age of structures	Percentage of structures older than 50yrs.	Older structures – high Vulnerability
12	Availability of infrastructure	Percentage of residence with infrastructure such as telephone	Poor infrastructure – high Vulnerability
13	Ownership of housing Unit	Percentage of occupied housing unit	Vacant housing unit – high Vulnerability
14	Rural/Urban	Percentage population in urban/rural	Clerical and service sector – high Vulnerability more urban- low Vulnerability.

Source: Cutter, Boruff and Shirley (2001) and Heinz Centre for Science, Economics and the Environment (2002).

Table 5: Graduated scale for social vulnerability indicators in Missouri

S/N	Social Indicator	Range of Values	Scores
1	Age	<20% <18 and >65yrs	1
		20 - 49% <18 and >65yrs	2
		≥50% <18 and >65yrs	3
2	Marital Status	<20% singles/separated	1
		20-49 % singles/separated	2
		≥ 50 % singles/separated	3
3	Education	<20% college degree	3
		20-49 % college degree	2
		≥ 50% college degree	1
4	Household Incomes	<20 % earn less than $35000	1
		20-49 % more than $35000	2
		≥ 50 % earn less than $35000	3
5	% Disability	<10% disabled	1
		10-15% disabled	2
		≥ 16% disabled	3
6	% Mobile Homes	<10% with mobile homes	1
		10-19% with mobile homes	2
		≥ 20% with mobile homes	3
7	Race/Ethnicity	≥70% white	1
		50-69% white	2
		<50% white	3
8	Language Spoken	≥70% speak English	1
		35-69% speak English	2
		<35% speak English	3
9	Insurance	< 10% without insurance	1
		10-19% without insurance	2
		≥19% without insurance	3
10	% Women	<25% Women	1
		25 -49% Women	2
		≥50 Women	3
11	Telephone	< 10% without telephone	1
		10-19% without telephone	2
		≥19% without telephone	3
12	Age of Structure	<20%: 50 years old	1
		20% – 49: 50 years old	2
		≥ 50%: 50 years	2
13	Tenancy (Renters)	<20% renters	1
		20 – 49% Renters	2

		≥50 %Renters	3
14	Unemployment	<10% Unemployed	1
		10-19% Unemployed	2
		≥20% Unemployed	3

3.3 Results and Discussion

The summary of social indicators and their contribution to social vulnerability to wildfire are presented in Table 6 and Figure 9**.** The results of the social vulnerability assessment of Missouri residents to wildfire indicators show a moderate vulnerability. Four indicators, namely income, education, ratio of day to night population and availability of telephone contribute more significantly to wildfire risk in Missouri. These variables all scored 3 in the vulnerability assessment, which is rated as high vulnerability.

Table 6: Estimation of social vulnerability index to wildfire in Missouri

Social Indicator	Southwest Missouri	Southeast Missouri	Central Missouri	Northeast Missouri	Northwest Missouri
Age	2	2	1	2	2
Marital Status	2	2	2	2	2
Education	3	3	2	3	1
Income	2	2	2	2	2
Disability	1	2	1	1	2
% Women	2	1	2	2	2
Telephone	1	1	1	1	1
Age of Structure	1	2	2	2	2
Mobile Homes	1	2	1	1	1
Tenancy	2	2	2	1	2
Employment Status	1	1	1	1	1
Race	1	1	1	1	1
Language Spoken	1	1	1	1	1
Insurance	1	2	1	1	2
Total Score	21	24	20	21	22
SoVI index	1.50	1.71	1.42	1.50	1.57

SoVI rating: (0-1) low Vulnerability; (1.1 – 2.0) moderate vulnerability, and (2.1 – 3.0) high vulnerability

Social Vulnerability Index (SoVI) = Total Score ÷ No of Indicators

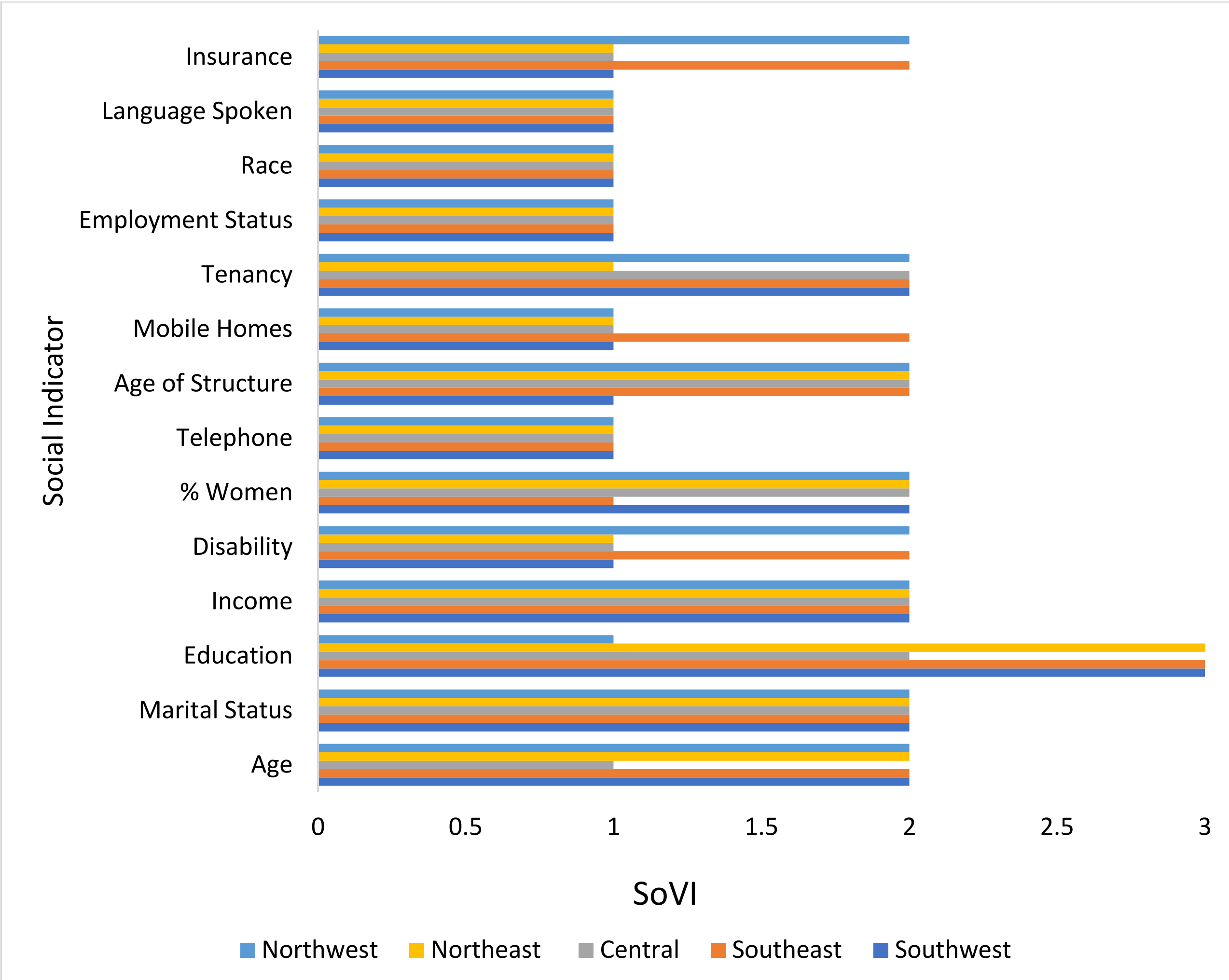

Figure 9: Chart of social vulnerability index to wildfire in Missouri

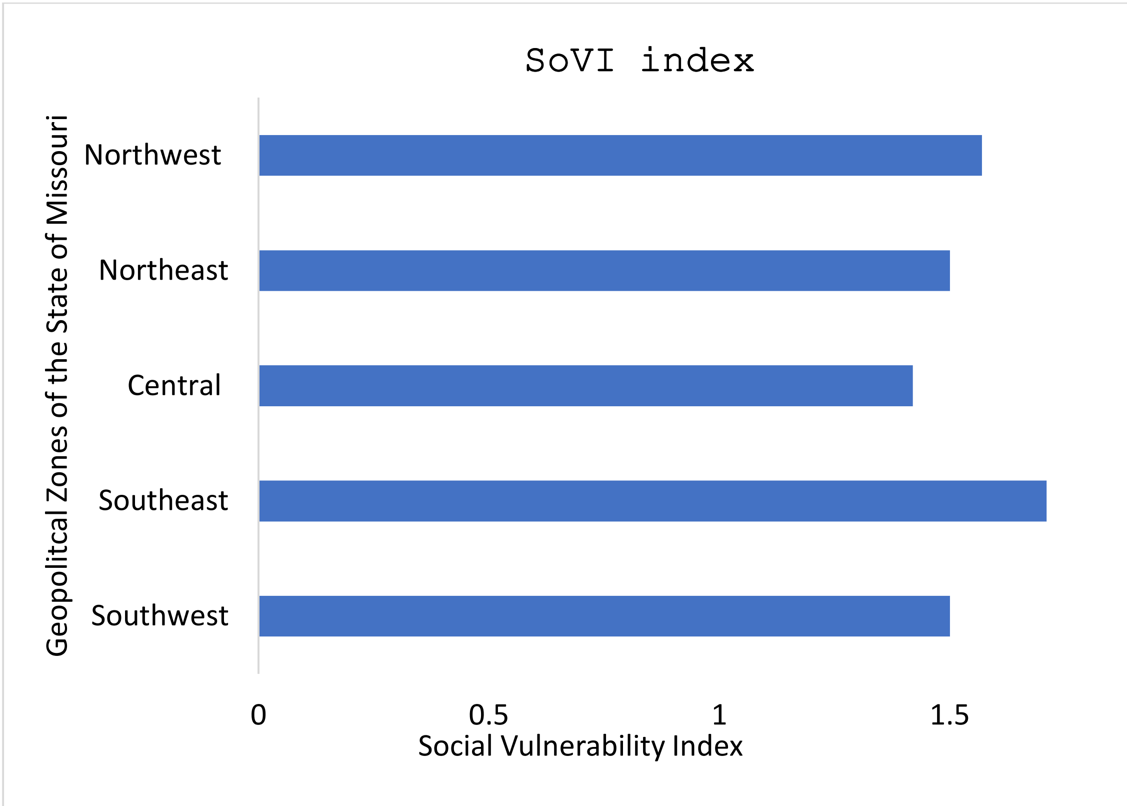

Figure 10: Comparison of SoVI of the geopolitical zones

Age, marital status, employment status, disability, age of buildings or structures and level of poverty which scored 2.0 contribute moderately to social vulnerability. However, race/ethnicity, language spoken, number in households and length of stay in residence scored low in social vulnerability index and they therefore positively contribute to resilience to wildfire risk in Missouri.

A comparison of social vulnerability indicators among the five geopolitical zones shows that they are all moderate but with higher values recorded in Southeast and Northwest geopolitical zones of Missouri as shown in Figure 10. The lowest SoVI value was recorded in Central Missouri.

These findings correlate with the works of Caroll et al., (2005); Collins, (2009, 2012) on the influence of socio and demographic characteristics on solid vulnerability of wildfire risk. Although it should be stated that income is just one of many socio demographic characteristics that scholars disagree about when discussing factors influencing social vulnerability. Others include educational level, length of tenure in an area, primary versus secondary house owner (Kanclerz & Dechano – Cevk, 2013; Martin et al., 2007).

It has also been observed that both socio demographics characteristics and perceptual factors continue to be the focus of literature on wildfire vulnerability and adaptive capacity. Figure 11 presented the different identified social indicators and their contribution to social vulnerability to wildfire. It is an extraction of the vulnerability segment from the BBC model showing the interaction of the component of vulnerability, exposure, susceptibility, and coping capacity (Birkmann, 2006).

Apart from race/ethnicity, language spoken (that is English language), number living in households and length of stay in residence which fall within the coping capacity component, and which contribute to resilience to wildfire risk, all the other indicators contributed to social vulnerability in Missouri.

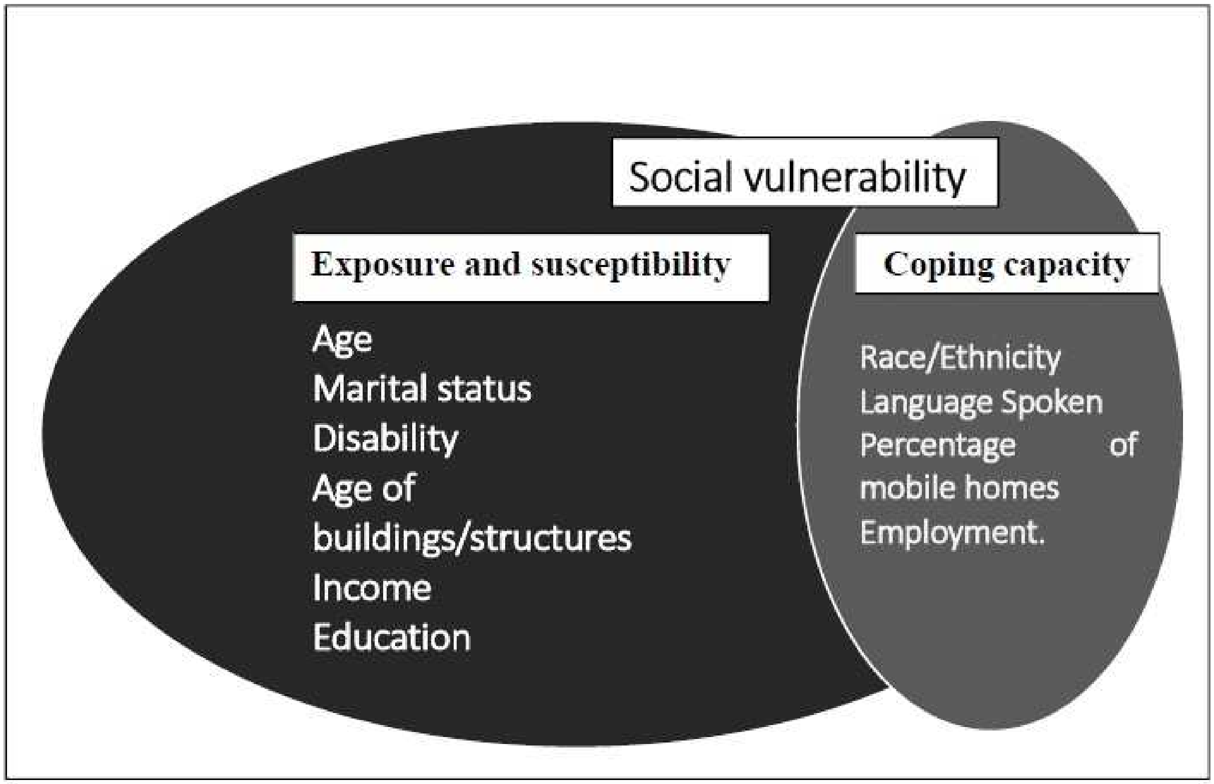

Figure 11: Summary of indicators using the BBC conceptual framework (Birkmann, 2006)

3.4 Conclusion and Recommendation

This study has assessed and identified the social vulnerability to wildfire in Missouri, United State of America using socio- demographics variables from the American Community Survey 2012-2016 data and SoVI. Results show that the social vulnerability of Missouri to wildfire is moderate. Income, education, availability of telephone, age, marital status, employment status, disability, age of buildings are the major vulnerability factors to wildfire risk in Missouri. Arising from this study, the paper recommended that Missouri should develop a state policy on wildfire risk reduction to guide countries and block levels. There is need for government to formulate a policy that will encourage more people to acquire education up to college degree. This may enhance their income and thereby increasing resilience to wildfire risk.

CHAPTER 4

4.0 CLIMATE AND WILDFIRE IN MISSOURI, UNITED STATES OF AMERICA

4.1 Introduction

One of the major environmental concerns in the United States and Missouri is the occurrence of devastating forest wildfires. It causes destruction to property lives and ecosystem. The relationship between meteorological conditions and fire occurrence is well known (Chandler, Cheney, Thomas, Trabaud, Williams, 1983). Forest fires tend to be concentrated in summer months when temperature is high and air humidity and fuel moisture are low especially in the Western United States. (Piñol, Terradas, & LIoret, 1998).

One approach to examine the relationship between fire occurrence and climate is by using meteorological fire hazard indices. The main problem in using these indices according to Piñol et al*.,* (1998) is that they must be applied to daily or even shorter periods, and that atmospheric relative humidity and wind data are necessary. Several scholars have investigated the possible impacts of global warning on wildland fire using fire behavior models and GCM predictions of future climate (Flannigan & Harrington, 1988; Flannigan, & Wagner, 1991; Torn & Fried, 1992; Davis & Michaelsen, 1995; Piñol et al., 1998). Few have examined whether the fire history of a region matches instrumentally observed variations in climate. The work of Balling, Meyer, & Wells, (1992a, b) on Yellowstone National Park after the devastating 1988 fire season is a classic example. A number of other studies have compared historical, tree-ring, lake-sediment charcoal, and other proxy records of fire with climatic proxy records over longer periods (Clarke, 1988; Meyer, Wells, Balling & Jull, 1992; Swetnam & Betancourt, 1990; Swetnam, 1993).

Westerling et al., (2003) observed that the number and extent of wildfires in the Western United States are driven by natural factors such as fuel availability, temperature, precipitation, wind, humidity and the location of lightning strikes, as well as anthropogenic factors. Other studies such as Simard et al., (1985), Swetnam & Betancourt (1990), Jones et al., (1999) have demonstrated that large-scale climate patterns in conjunction with El Nino affect the frequency and extent of wildfires that occur in particular regions of the United States. Swetnam and Betancourt (1998) and Balling et al., (1992) have found relationships between the Palmer Drought Severity Index (PDSI) and fire season severity.

This study relates monthly area burned by wildfire to simple meteorological variable. The objective is to determine the extent to which the variance in area burned is explained by this variable, and to developed insight into the causes of very severe fire months, and to develop a statistical description of weather condition associated with severe/high fire months.

4.2 Study Area and Methodology

Missouri has a continental type of climate marked by strong seasonality. In winter, dry-cold air masses in hundred by any topographic barriers, periodically swing south from the northern plains and Canada. If they invade, reasonably humid air, snowfall, and rainfall result (Decker, 2019). During summer moist, warm air masses swing north from the Gulf of Mexico, and can produce copious amount of rain, either by fronts or by convectional processes. High pressure may stagnate over Missouri during summer creating extended drought condition.

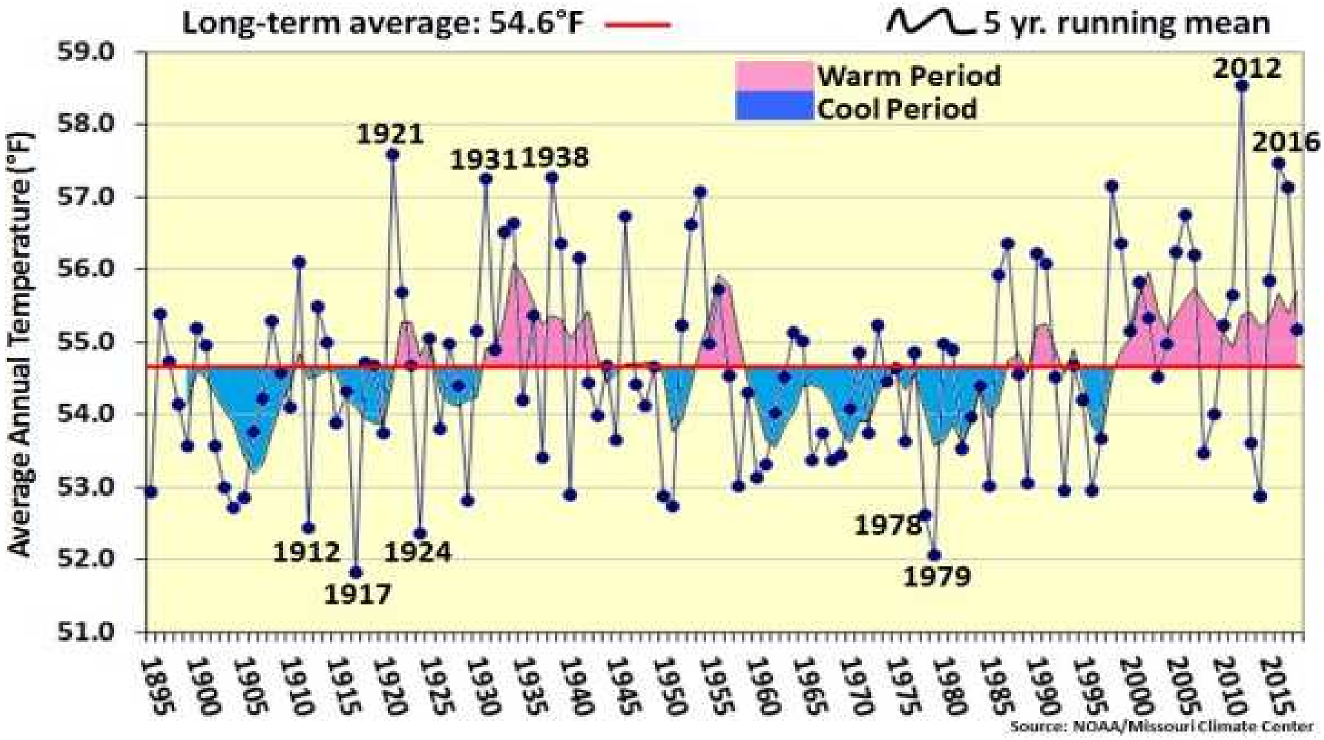

Figure 12: Missouri average annual temperature (1895-2018)

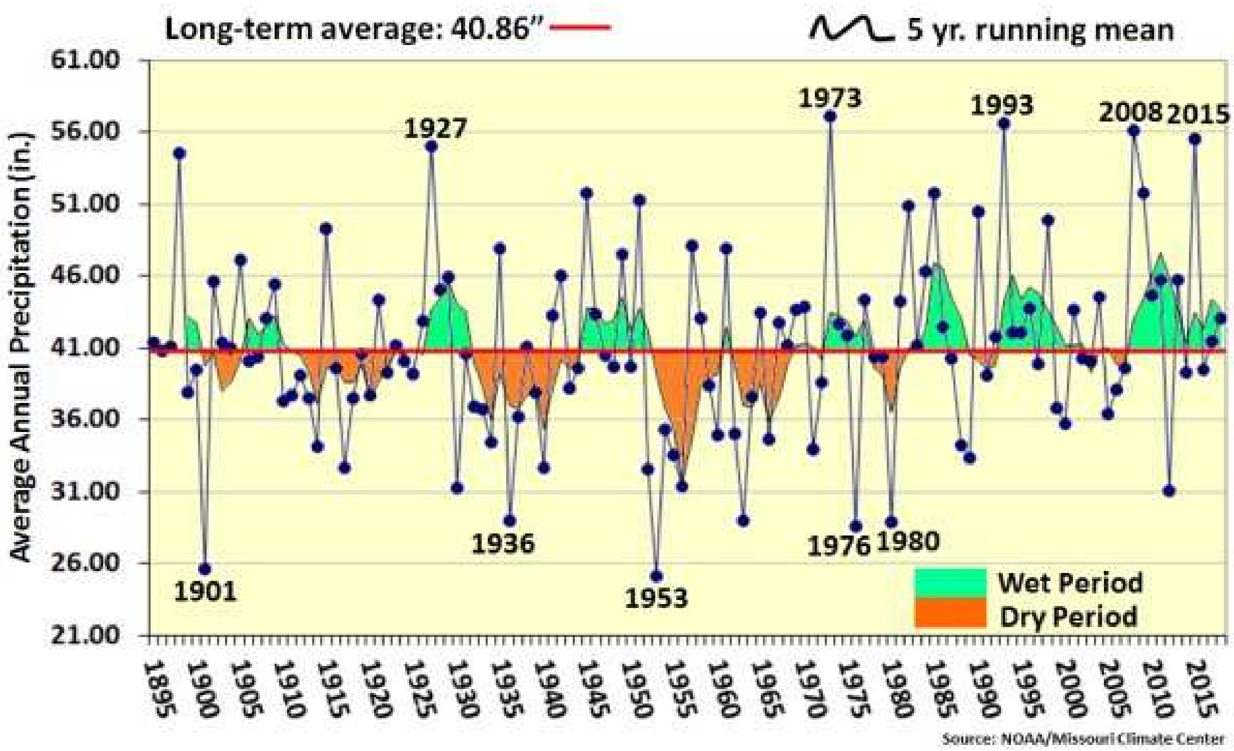

Figure 13: Missouri average annual precipitation (1895-2018)

Spring and fall are transitional seasons when abrupt changes in temperature and precipitation may occur due to successive, fast-moving fronts separating contrasting air masses (Decker, 2019). Figures 12 and 13 show Missouri average annual temperature, and average annual precipitation from 1895 to 2018. Figure 12 shows that Missouri has experienced fluctuating warm and cold period, and figure 13 showing alternating wet and dry period.

Data on monthly temperature from 1995 to 2018 were obtained from the Missouri Department of Environment while data on wildfire were obtained from the Missouri Department of Conservation. The temperature and wildfire data were correlated using Pearson correlation analysis.

4.3 Results and Discussion

4.3.1 Seasonality of Wildfire

Figure 14 shows the average burned area per year by wildfire in Missouri. The figure shows that though wildfire severity in terms of area burned was higher between 1940 and 1960, with a decline in the 1970s, area burned has increased in recent time since 2010. Figure 15 shows frequency of wildfires and total acreage burned per year with the causes of wildfire in Missouri between 1999 and 2008; while Figure 16 shows wildfires per year by size in Missouri (1999 – 2008). Figure 17 (a - d) and 18 show the seasonality of wildfire in Missouri based on data from Missouri Department of Conservation (1995-2018). It can be deduced from Figure 17(a - d) and 18 that wildfire in Missouri is seasonal with 90% of wildfires and 94% of area burned occurring between January and May. Peak occurrence occurs between the months of April and May.

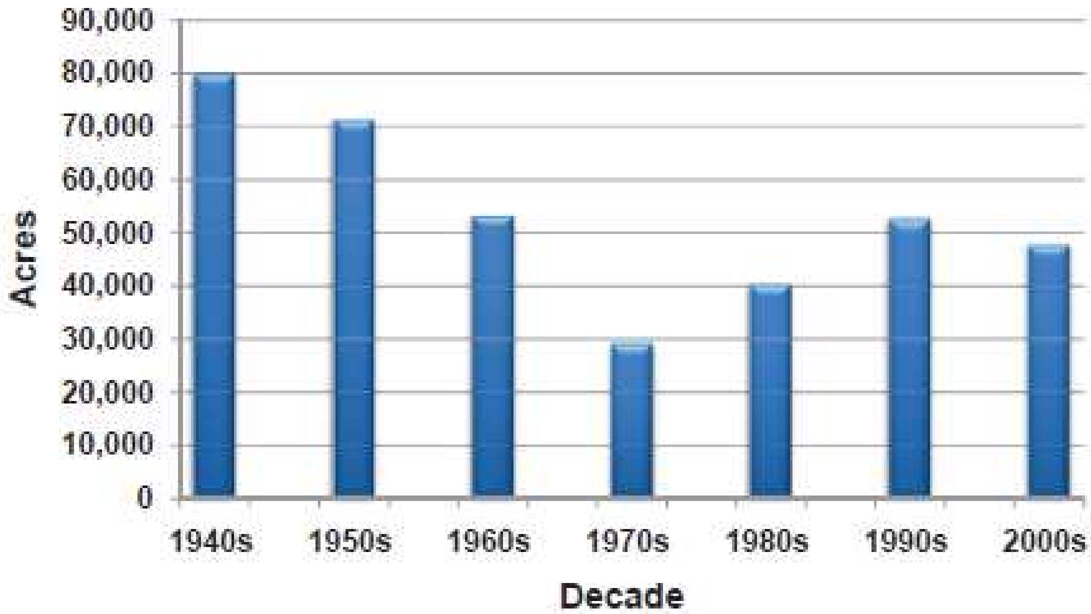

Figure 14: Average acres burned per year by wildfire in Missouri (1940-2008) data from Missouri Department of Conservation (MDC)

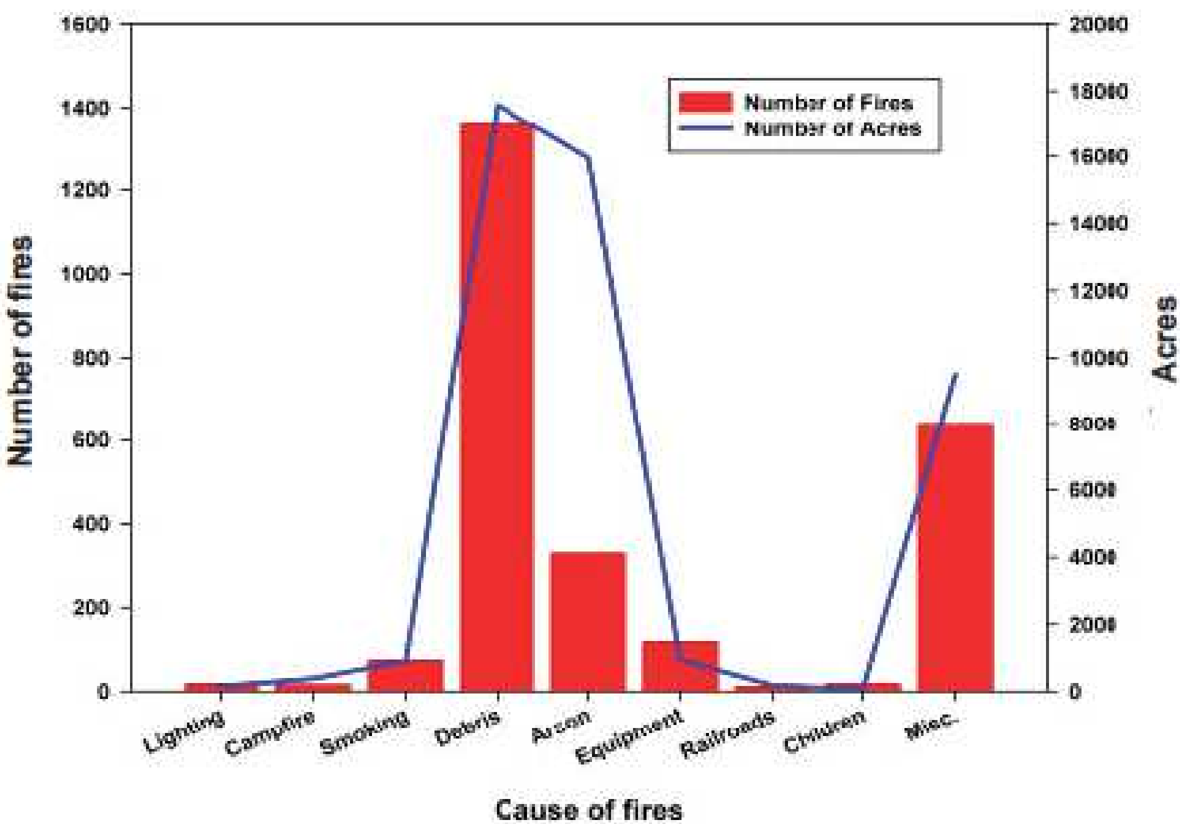

Figure 15: Wildfires and total acreage burned per year by cause in Missouri (1999-2008)
Source: Missouri Department of Conservation (MDC), 2008

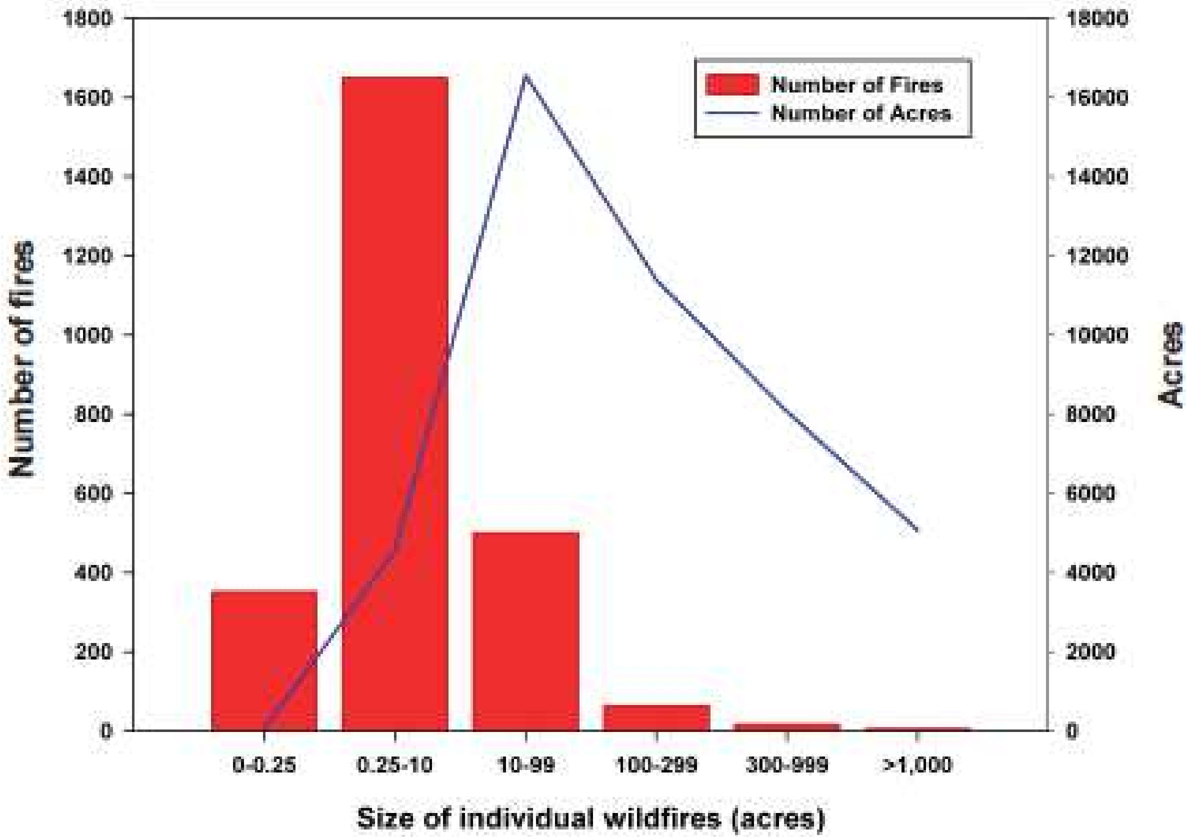

Figure 16: Wildfires per year by size in Missouri (1999-2008)
Source: Missouri Department of Conservation, 2008

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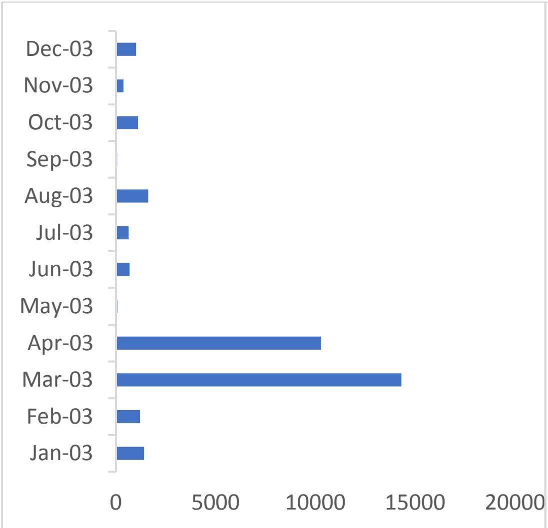
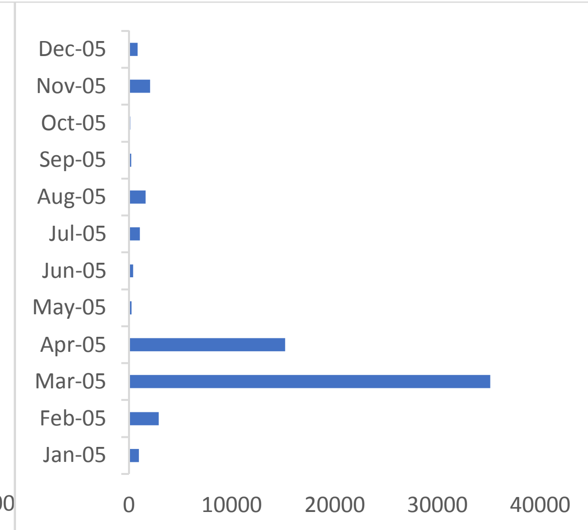
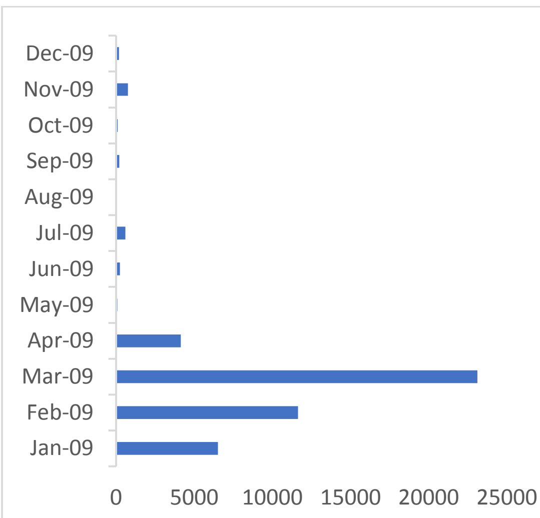


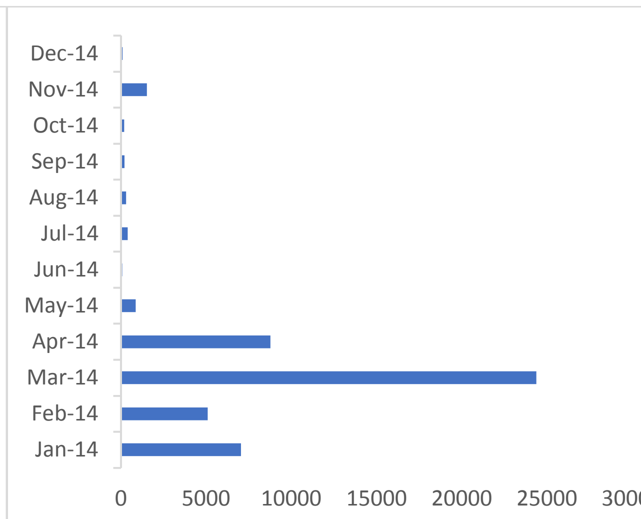
January to April, 2003 (a)



January to April, 2005 (b)



January to April, 2009 (c)



January to April, 2014 (d)

Figure 17: Seasonality of wildfire in year (a) 2003 (b) 2005 (c) 2009 and (d) 2014

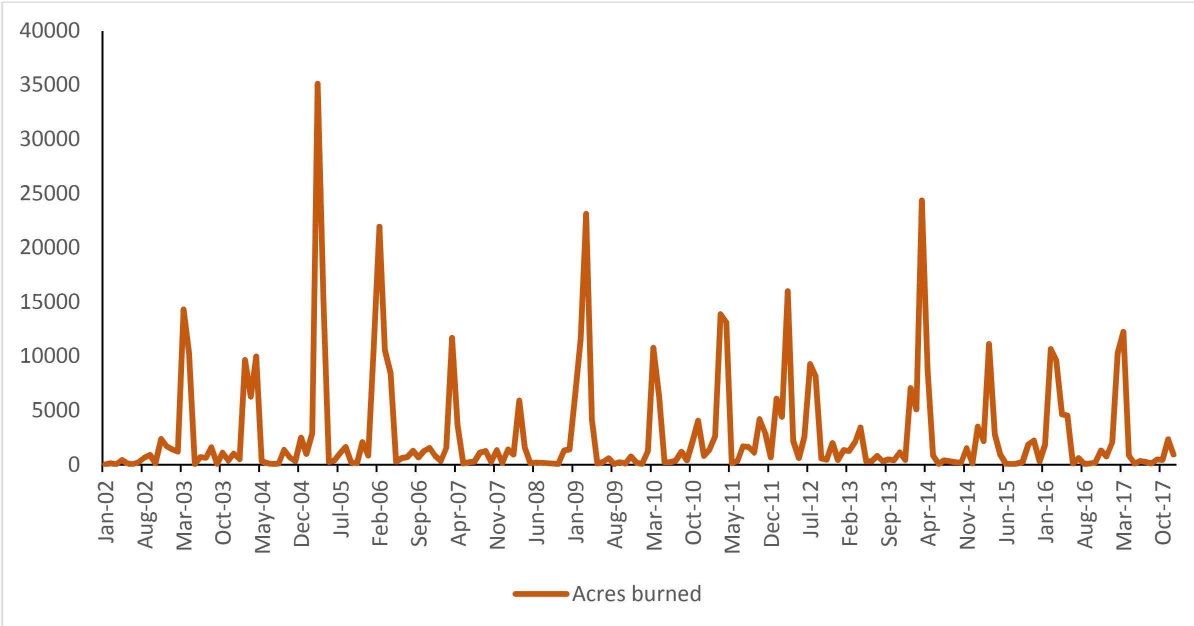


Figure 18: Seasonality of wildfire in Missouri, USA

4.3.2 Correlation of Climate and Wildfires

Figure 19 and Table 7 show the result of correlation between area burned and temperature from 1995 to 2018. Result shows that a correlation coefficient 0.0771 was obtained. This indicates that there is no significant positive relationship between area burned and temperature.

Data from Missouri Department of Conservation (2008) shows that lightning accounts for only 1% of wildfire in Missouri, whereas lightning (from thunderstorm) accounts for 2/3 of Western wildfires in the United States. So, it is not a surprise that climate especially temperature did not significantly correlate with wildfire occurrence in Missouri. It was observed from the literature that arson contributes 40% of the cause of wildfire in Missouri.

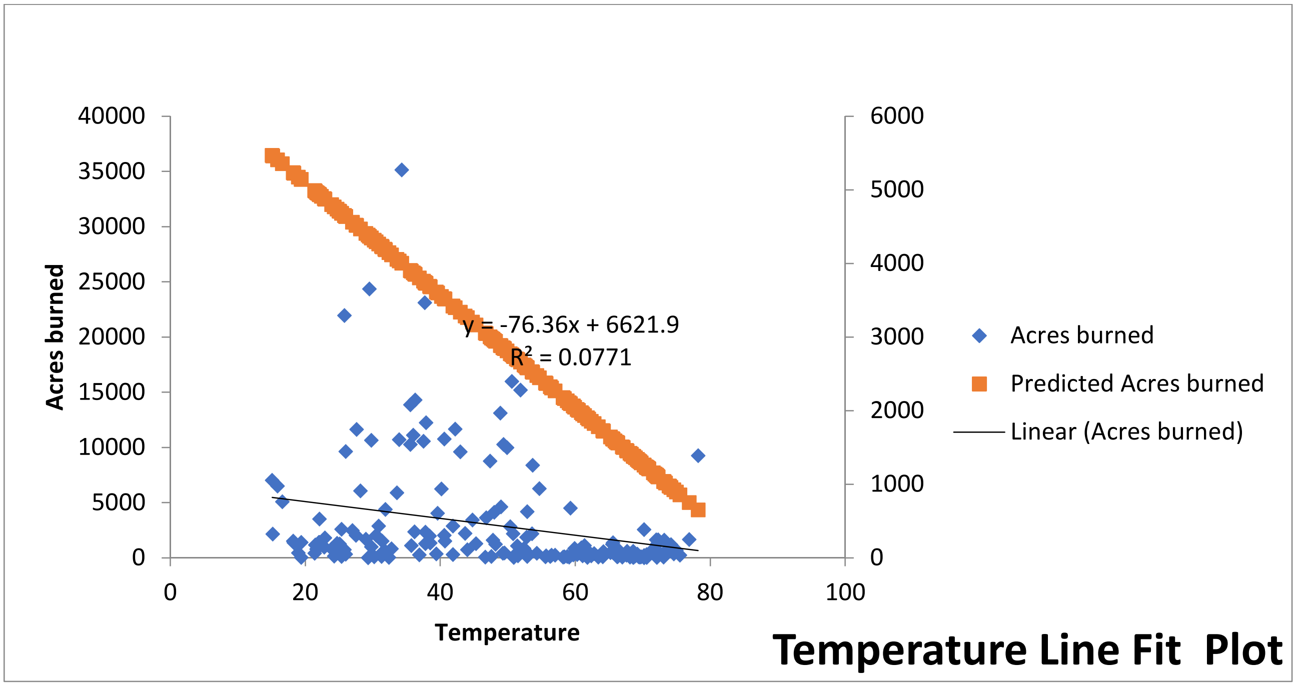


Figure 19: Result of correlation between area burned and temperature from 1995 to 2018

Table 7: Correlation between acres burned and temperature

Correlation		
	Acres burned	Temperature
Acres burned	1	
Temperature	-0.277649254	1

4.4 Conclusion

The study has examined the area burned in Missouri from 1940 to 2008. It has also considered the seasonality of wildfire in Missouri. Results show that wildfire occurs between January and July, with peak occurrence in May. The result of the correlation analysis between wildfire and climate using Pearson correlation analysis shows that there is no correlation as a correlation coefficient of 0.0771 was obtained. This result further confirms the previous report by Missouri Department of Conservation that lightning from thunderstorm constitutes only

1% the cause of wildfire in Missouri. This is unlike the Western United States where climate is a major cause of wildfires. The study concludes that arson appears to be a major cause of wildfire in Missouri.

CHAPTER 5

5.0 WILDFIRE POLICY CHALLENGE IN THE UNITED STATES: IMPLICATIONS FOR WILDFIRE RISK REDUCTION IN MISSOURI

5.1 Introduction

The policy challenge caused by wildfires is a major source of concern in the United States (Busenberg, 2004). The destructive effects of wildfire in the United States have led to loss of lives, damage to property, and loss to ecosystem, tourism, timber and even air quality (GAO, 1999a, 1999b, 2000; United States Department of Agriculture (USDA) Forest Service and United State Department of the Interior (DOI), 2000; USDA Forest Service, 2000. The cost of firefighting is also on the rise. It was estimated that over $2 billion were incurred to firefighting in 2000 alone. In Missouri, wildfire is still a major challenge because of the destruction to property and ecosystem. Figure 20 shows the average acres burned from 1940s through 2008. Figure 21 shows wildfires and total average burned, and Figure 22 shows wildfire per year by size. In order to reduce or mitigate this trend, the United States put in place a number of wildfire policy framework. The objective of this paper is to examine some of the wildfire policy in the United States; analyze the current challenges facing their implementation, consider the implication of these for wildfire risk reduction in Missouri.

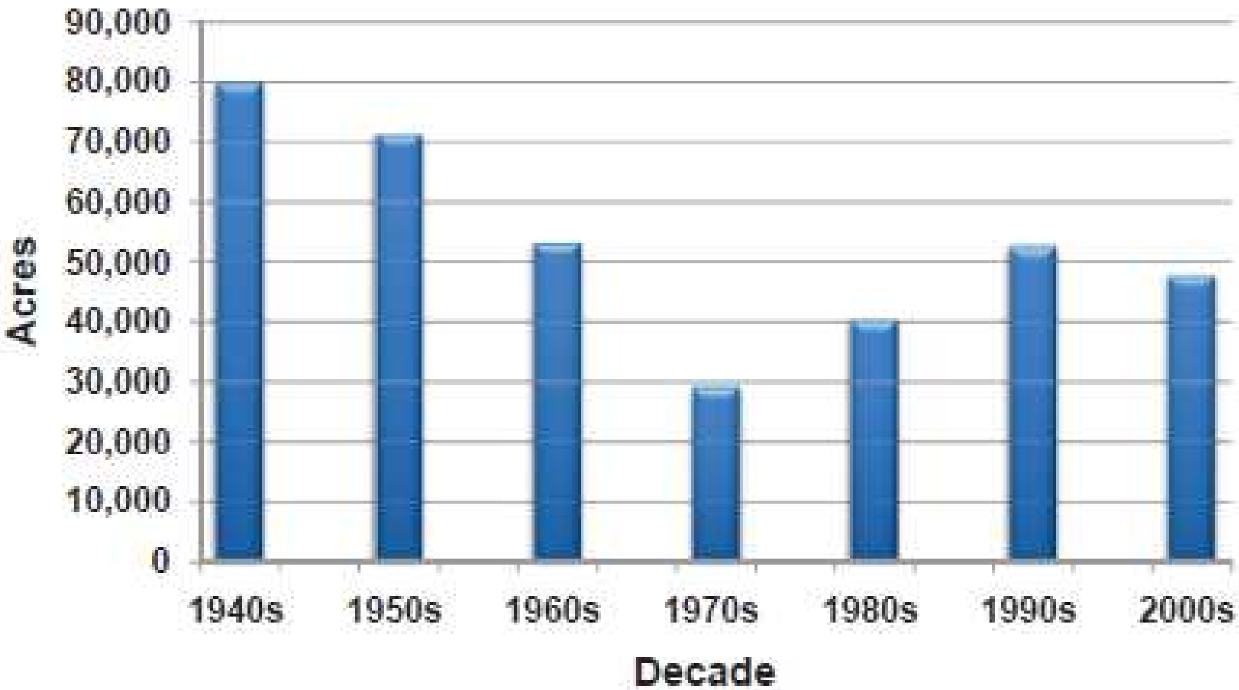


Figure 20: Average acres burned per year by wildfire in Missouri (1940-2008)
Source / Data from Missouri Department of Conservation (MDC)

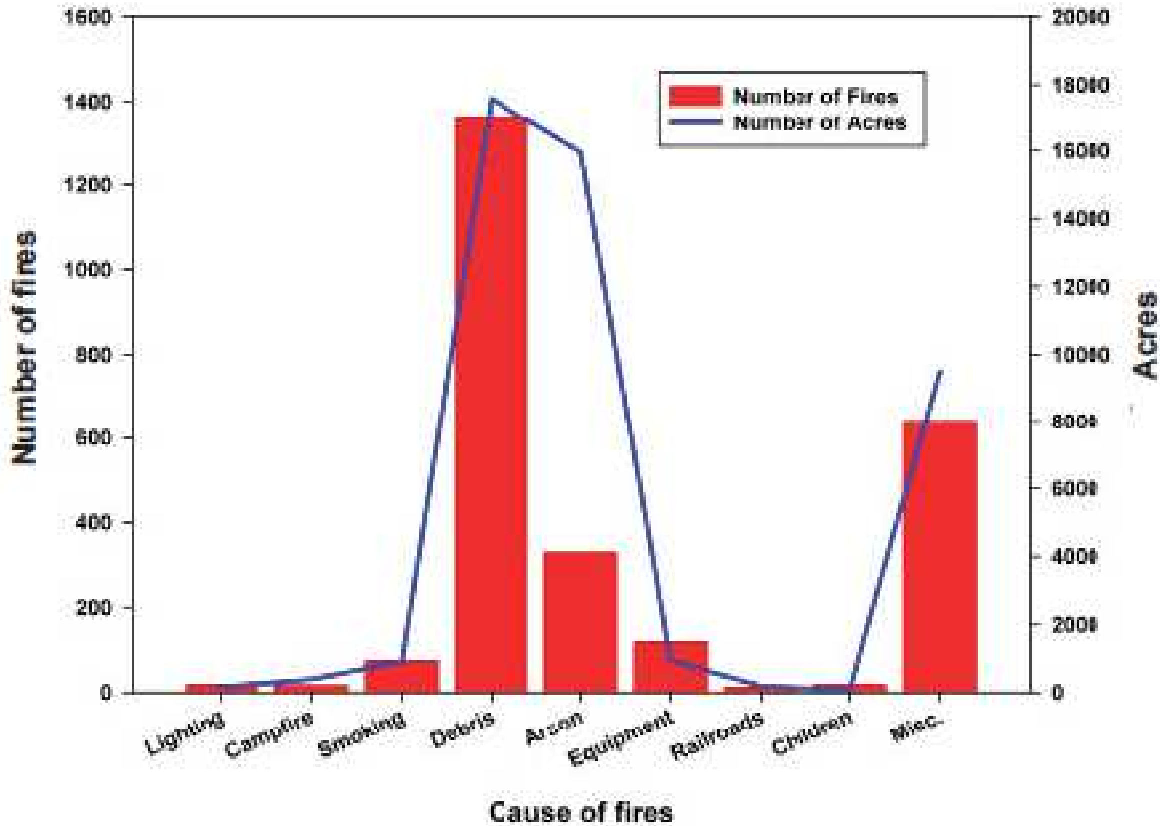


Figure 21: Wildfires and total acreage burned per year by cause in Missouri (1999-2008)
Source: Missouri Department of Conservation (MDC), 2008

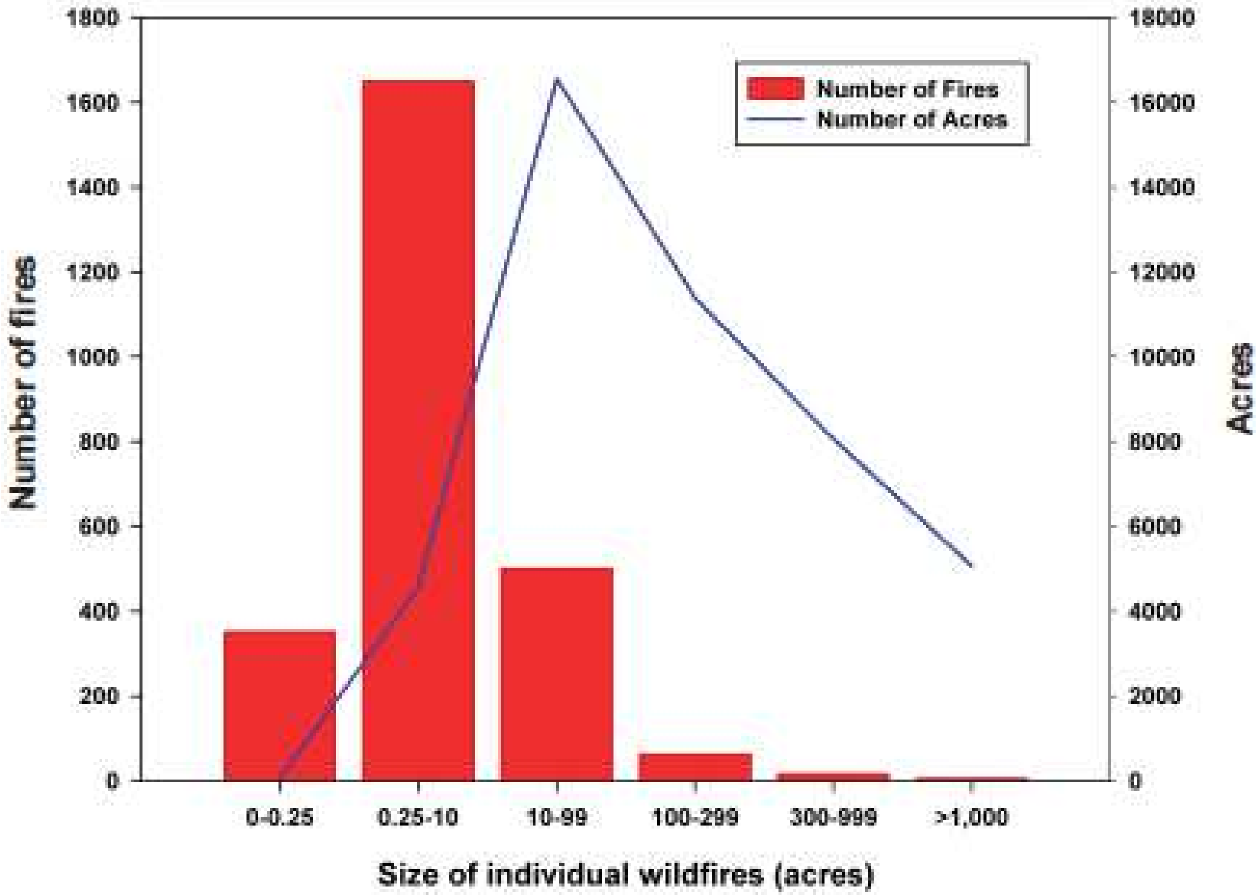


Figure 22: Wildfires per year by size in Missouri (1999-2008)
Source: Missouri Department of Conservation, 2008

5.2 Wildfire Policy in the United States

According to Steelman and Burke (2007) observed that the wildfire suppression policy is the first policy wildfire policy that was established in 1905. This policy was in operation for five decades, the policy failed to include ways to mitigate highly inflammable organic materials that were systematically over accumulated over time. The consequences of this over accumulation is that wildfires intensity became extremely high and this has accelerated the damaging potential of wildfires in American wildland. (USDA Forest Service, 2000; USDA

Forest Service and DOI, 2000; GAO, 1999a, 1999b; National Commission in Wildfire Disasters, 1994).

Fire suppression involves aggressive firefighting. Aggressive firefighting alone cannot solve the wildfire problem (USDA Forest Service and DOI, 2000). The general believe is that firefighting has never proved to be an effective strategy for fuel-load reduction. This strategy has gained acceptance as a major approach for mitigating wildfire hazards. There are practical challenges with fuel reduction, this is the reason why mechanical fuel removal and prescribed burn are alternatives for fuel reduction. Apart from air pollution problem caused by prescribed burning, it has been discovered that there are problems arising from damage to ecosystem and human community (Busenberg, 2004). Effective fire-mitigation approach requires a lot of manpower and equipment over a period of time (Davis, 2006).

In addition to this, there is issues of transboundary policy regarding wildfire. This is because wildfires do not recognize geographical and political boundaries. Arising from this, there is need for close collaborations among various stake holders and individuals whose activities are impacted by wildfires (Busenberg, 2004; Davis, 2001, 2006; Western Governors' Association (WGA), USDA, and DOI, 2001). This is what made Busenberg, (2004) to conclude that the present institution arrangement has not reduced wildfire but has created more ecological problems, prevention of wildfire has therefore remained complex, expensive, and risky.

5.3 Recent Wildfire Policy Changes

In recent time, the over emphasis on wildfire suppression policy alone has been found to be inefficient. Steelman and Burke (2007) observed that in the fall of 2000, a recommendation aimed at mitigating the adverse effects of wildfires on settlements and the environment as well as guaranteeing enough resources for future firefighting was submitted to President William J. Clinton. This recommendation and the attendant congressional appropriations led to the formulation of technical and financial strategies, guidelines, and projects which today is referred to as the National Fire Plan (NFP). This $10 billion and 10-year effort plan aimed at restoring forest ecosystems and human settlements. (Steelman & Burke, 2007).

In 2001, Congress in collaboration with Western Governors' Association (WGA) developed an organized national 10-year comprehensive approach for carrying out National Fire Plan (NFP). The NFP and the WGA 10-year comprehensive strategy identified some major objectives for mitigating the risk of wildfire and establishing collaboration at all governmental levels. These are to:

- Enhance fire prevention and suppression,
- Lessen hazardous fuels,
- Rebuild fire adapted ecosystems, and
- Encourage community assistance (WGA, 2001).

These efforts represent the first major attempt at shifting focus from wildfire suppression toward long term policies of protecting the natural environment and health of human settlement.

Steelman and Burke, (2007) argued that in 2002, the Healthy Forests Initiatives (HFI) was introduced by President George W. Bush. This initiative involves series of reforms aimed at improving the administrative bottlenecks, legislative actions, and procedural delays in implementing fuels reduction projects in the United States on up to 20 million acres of federal land.

The central focus of the HFRA is the Community Wildfire Protection Plan (CWPP). The idea is that for any community to have access to funding from the HFRA, the community should possess a CWPP. These CWPP arrangement is to bring together relevant stakeholders to develop a blueprint for tackling dangerous fuels in the Wildland Urban Interface (WUI). The intension of the CWPP according to Newman (2004) is to give local people disturbed by wildfire a sense of belonging in government mitigation management plans, and to give communities a sense of participation in wildfire risk management.

5.4 Challenges in the Implementation of Wildfire Policy in the United States

There are funding challenges in the implementing of wildfire fuel reduction policy. Increase in funding for hazardous fuel reduction has failed to be proportionate with the amount proposed by Congress in the HFRA. Majority of the National Fire Plan (NFP) funding in each state in the United States since 2001/2002 were allocated to firefighting purposes and hazardous fuels treatments (Steelman, Kunkel, & Bell, 2004. Only a smaller percentage were allotted to ecosystem restoration and community support.

Also, collaborative frameworks which is the central focus for executing the NFP and the 10-year comprehensive strategy, is not being utilized steadily at the local, state and national levels (WGA, 2004). Furthermore, collaborations at the state and regional level are not inclusive enough especially at national level as it does not provide significant involvement of non-federated collaborators (Daly, 2004; WGA, 2004; Gregory, 2005; Delaco, 2006). It has also been reported by Jensen (2006) that ground plan from CWPPs, which are meant to reorder wildfire alleviation approaches at different levels of government are not really implemented.

The major challenges confronting wildfire policy implementation in the United States can be summarized as lack of economic support and technical resources, non-appreciation of stakeholders achievements, inexperienced of agency employees, and unwillingness to innovation in the forest service (Daly 2004; Gregory, 2005; Delaco, 2006). There is also the legal challenge in expediting hazardous fuels treatments. The current approach still favors fire suppression and hazardous fuels reduction, and this creates partial remedy to the wildfire mitigation question. There is need to give the required institutional and financial attention they require.

5.5 Critical Factors for Forest Fire Risk Reduction and Management in Missouri

The first sector to consider is the social and demographic characteristics of the forest landowners in Missouri. This is very critical to wildfire risk mitigation. The aged population, income and low education are factors that enhance wildfire risk. Most of Missouri's forest are privately owned (see Figures 23 & 24). About one-third of the private forest landowners are absentee owners because they do not live near their forest land, this increases forest fire incidence, only 32% of them have college degrees, and 34% are older than 65 years. These social and demographic characteristics of forest landowners have not encouraged wildfire risk mitigation efforts and management.

Table 8: Social and demographic characteristics of forest owners in Missouri

Forest Owners	New owner: 26 % have purchased their forest land within the last 5 years
	Absentee owners: 32 % do not live on a near (within 1 mile) their land
	Farmers: 38 % have a farm associated with their forest land
Age	12 % are less than 45 years old
	54 % are 45 to 64
	34 % are 65
Education	32 % have college degree
Annual household income	55 % - under $50,000
	27 % - $50,000 to $100,000
	18 % $100,000 or more

Source: Butler 2008

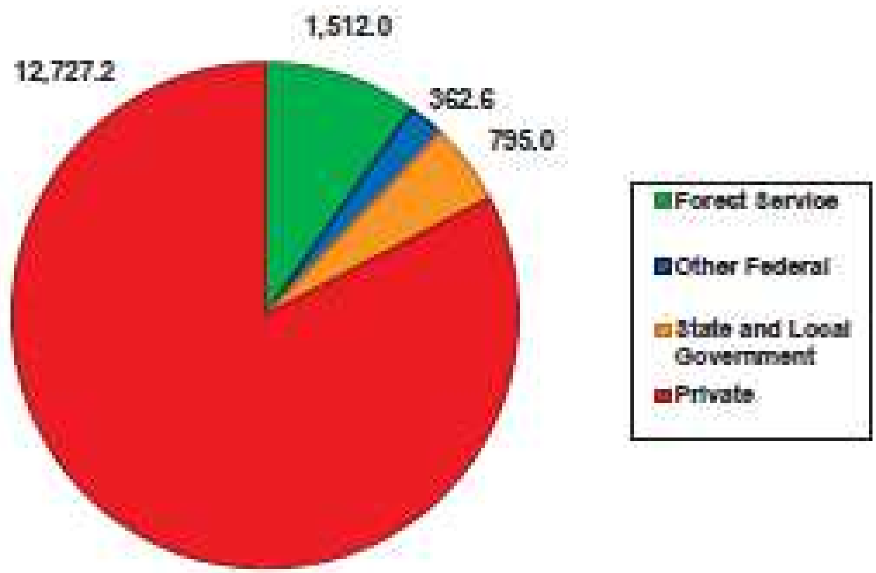


Figure 23: Missouri forest land ownership by major ownership group, in thousands of acres. *Source: Butler, 2008*

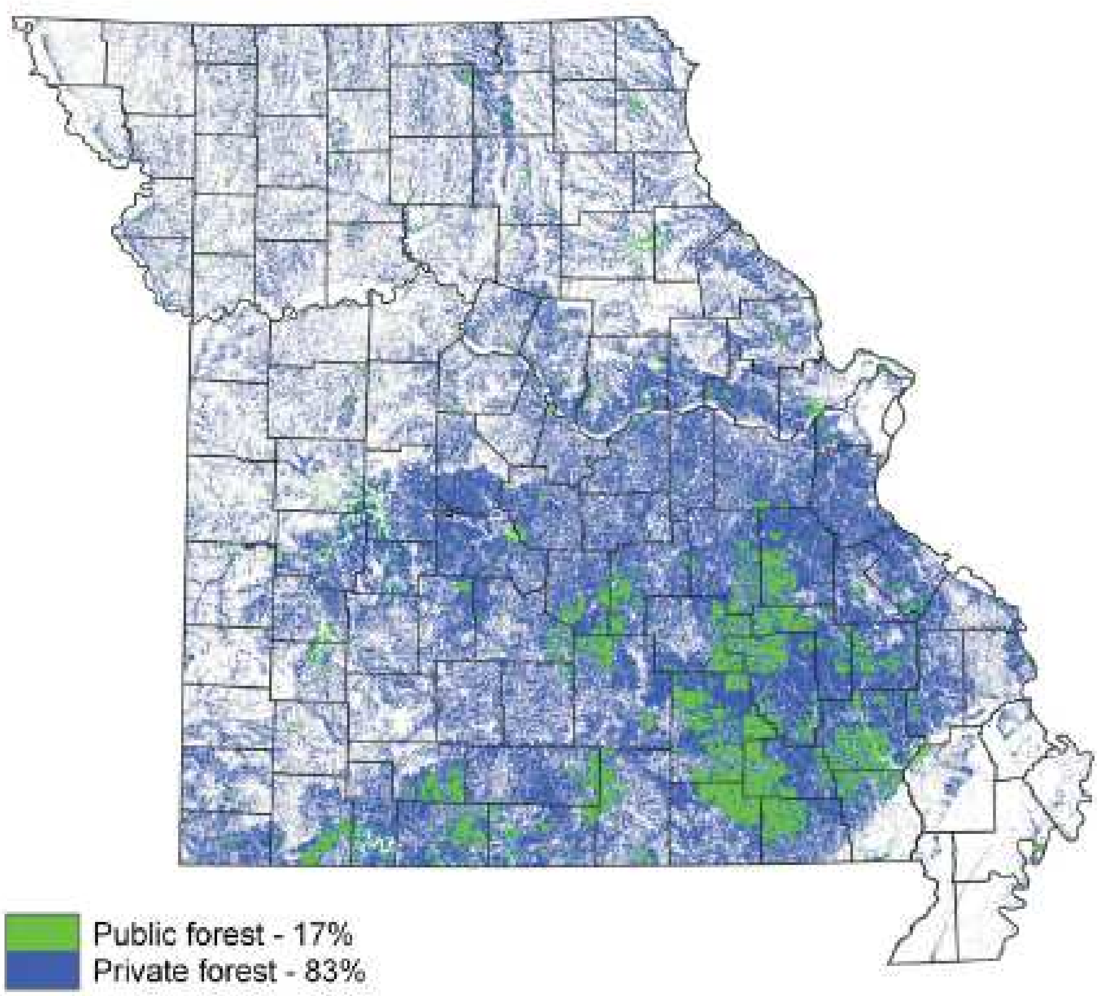


Figure 24: Forest land in Missouri by major owner group. Source: Map by Dacia Meneguzzo, U.S. Forest Service, Northern Research Station 2008
Source: Missouri Department of Conservation, 2008

All these social and demographic characteristics of forest landowners have policy implication for wildfire risk and management. The aged population, income and low education are factors that enhance wildfire risk.

Secondly, land use change in Missouri is another critical factor in wildfire risk reduction/management. The way land is from one generation of landowners to another have implications for forest fire occurrence and management.

Thirdly, recent changes in climate particularly precipitation exacerbates the severity of wildfire change. Missouri located in the hinterland has been observed has a region that will suffer from extreme drought condition. This will have implication for increase wildfire occurrence as the climatic condition becomes warmer (Intergovernmental Panel on Climate Change (IPCC) 2001).

In addition, the development of human settlements at the Wildland-Urban Interface (WUI) have led to the increase of wildfire occurrence in Missouri. This has made people and property at risk and created additional challenges to firefighters. Finally, the bureaucracy involved in implementing and complying with environmental regulations have been recognized as a major constraint to the ability of firefighters in mitigating the risk of wildfire to communities in Missouri (Steelman & Burke, 2006).

In conclusion, it has been observed that at present, Missouri does not have any State Wildfire Policy in place to tackle the Menace of Forest fire unlike states of California and Arizona. Such a wildfire policy when put in place should consider or take into cognizance the peculiarities of social and demographic characteristics of forest landowners in Missouri, Land Use Change, issues associated with Wildland Urban Interface (WUI) Climate Change, and Law prohibiting arson. These in addition to fuel load reduction as well as implementing Community Wildfire Protection Plan (CWPP). These in our view are challenges to be resolved in formulating an effective wildfire risk preparedness, prevention, reduction, mitigation and response strategies for Missouri.

CHAPTER 6

CONCLUSION

The study deals with geo-information-based model for assessing and monitoring of forest fire risk in the state of Missouri, U.S.A. The essence is to help mitigate forest fire disasters to terrestrial environment, and economic destruction to Missouri residents that are prone to forest fires. It also assessed and identified social vulnerability of Missouri residents to wildfire risk in order to develop a wildfire a policy for reducing wildfire risk and losses in the study area.

The following findings can be deduced from this research:

First, this research has successfully applied a risk index based on forest fire hazard and vulnerability factors for the assessment of forest fire vulnerability zones in Missouri, United States. This risk index is based on parameters such as topographical/ relief map, vegetation map, forest types, forest density and housing density map. An assessment of the forest fire vulnerability zone for forest resource management on a predetermined set of eight criteria delineated the State of Missouri into three forest fire risk zones, high forest fire risk, moderate forest fire risk and low forest fire risk zones.

Second, this research also assessed and identified the social vulnerability to wildfire in Missouri, United State of America using socio- demographics variables from the American Community Survey 2012-2016 data and SoVI. The scale of study is at sub regional level of Missouri. The state of Missouri was divided into geopolitical zones as defined by the government of Missouri. These are Southwest Missouri, Southeast Missouri, Central Missouri, Northwest Missouri and Northeast Missouri. Ten counties were randomly selected for study in each geopolitical zone to obtain the composite value for each zone. Identification of variables and interpretation of results in this study were based on the BBC framework by Bogardi, Birkmann and Cardona (see Figure 8). The term "BBC" framework comes from the conceptual model developed by Bogardi and Birkmann (2004) and Cardona (1999, 2001). Results show that the social vulnerability of Missouri to wildfire is moderate. Income, education, availability of telephone, age, marital status, employment status, disability, age of buildings are the major vulnerability factors to wildfire risk in Missouri. However, race/ethnicity, language spoken, number in households and length of stay in residence scored low in social vulnerability index and they therefore positively contribute to resilience to wildfire risk in Missouri.

Furthermore, the research also correlated monthly area burned by wildfire to climate variable. This was to determine the extent to which the variance in area burned is explained by this variable, and to develop insight into the causes of very severe fire months, and if there is any association with severe/high fire months. The result of correlation between area burned and temperature from 1995 to 2018 shows a correlation coefficient of 0.0771. This indicates that there is no significant positive relationship between area burned and temperature. This result further confirms the previous report by Missouri Department of Conservation that lightning from thunderstorm constitutes only 1% the cause of wildfire in Missouri. This is unlike the Western United States where climate is a major cause of wildfires. The study has also examined the area burned in Missouri from 1940 to 2008 and considered the seasonality of wildfire in Missouri. Results show that wildfire occurs between January and July, with peak occurrence in May.

Additionally, to have wildfire risk mitigation policy in place in Missouri, it is very critical to consider the social and demographic characteristics of the forest landowners in Missouri. It has been stated in the literature that most of Missouri's forest are privately owned and of this private forest land, most are owned by families and individuals and about thirty percent of the private forest landowners are absentee owners because they reside far from their forest land, this bring rise to frequencies of forest fire incidence (Butler, 2008). The social and demographic characteristics of forest landowners have policy implication for wildfire risk and management. The aged population, income and low education are factors that enhance wildfire risk. Land use change and recent changes in climate particularly precipitation exacerbates the severity of wildfire change in Missouri. The way land is being used from one generation of landowners to another have implications for forest fire occurrence and management. The implication climate change will increase wildfire occurrence as the climatic condition becomes warmer (Intergovernmental Panel on Climate Change (IPCC) 2001). The increase in the number of people living at the Wildland-Urban Interface (WUI) have led to the increase of wildfire occurrence in Missouri. This act has made people and property at risk and created additional challenges to firefighters. Finally, the bureaucracy involved in implementing and complying with environmental regulations have been recognized as a major constraint to the ability of firefighters in mitigating the risk of wildfire to communities in Missouri (Steelman and Burke, 2006). It has been observed that at present, Missouri does not have any state wildfire policy in place to tackle the menace of forest fire unlike states of California and Arizona.

In conclusion, this study successfully produced forest fire risk maps from the application of geo-information-based model for assessing and monitoring of forest fire risk in the state of Missouri, U.S.A. These maps can be used for effective and sound decision-making process in the forest management in Missouri and thereby minimize threats to life, property, and natural resources.

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VITA

Omolola V. Akinola was born in Ilesa, Osun State, Nigeria. She had her primary and secondary school education in Ilesa and Osogbo respectively. She started her Interdisciplinary Ph.D. (IPhD) program at the University of Missouri, Kansas City (UMKC) with Earth and Environmental Sciences as primary discipline and Social Science Consortium as a co-discipline in Fall 2015. Omolola completed undergraduate and graduate studies and earned a B. Tech degree (2008) in Forestry and Wood Technology and M. Tech (2012) degree in Forest Resources Management from the Federal University of Technology, Akure (FUTA), Nigeria. On the strength of her scholarship and impressive academic credentials, she was retained in the same institution as an Assistant Lecturer, having graduated as one of the top 5 students in her class. While developing her career, she enrolled in the Professional Master's degree program of the United Nations supported Regional Training Center in Aerospace Surveys (RECTAS) in 2013 and graduated as the best student in Geoinformation Production and Management. Omolola taught several undergraduate courses at FUTA, including Application of GIS in Forest Resources Management, Introduction to Remote Sensing and Geographic Information System, Biometrics, Environmental Impact Assessment and Introduction to Forest Resources Management. Prior to coming to UMKC, Omolola also served as 2nd year undergraduate students' academic advisor at FUTA from 2012 to 2015.

Omolola self-sponsored herself to UMKC before she got UMKC College of Arts and Sciences and Department of Geosciences funding as Graduate Teaching Assistantship in August 2016 till date. Omolola is a Shear Fellow (Sue Shear Leadership Academy for Women in Public Life at UM-St. Louis, 2018). She is also a member of several learned societies including the American Association of Geographers (AAG), UMKC Women in Science, Forestry Association of Nigeria, Nigeria Institute of Management (NIM), Forests and Forest Products Society (FFPS), and the Nigeria Environmental Society (NEM), among others.

During her research, she was awarded University of Missouri-Kansas City, School of Graduate Studies Research Award Program (August 2018 - May 2019), Emerging Scholar Award for the 2020 Climate Change: Impacts & Responses Conference, 16th - 17th April, in Venice, Italy and travel grants to national and international conferences. Her research focuses on a Geo-information based assessment of forest fire risk in Missouri State, United States of America. She is currently exploring the application of geospatial technology in forest fire management and assessment of the co-effects of land use/land cover change and climate change on wildfire/biodiversity/forest resources. She has attended several academic conferences and has a number of journal publications as well as chapter contributions in edited books to her credit.

PEER REVIEWED JOURNALS

1. **Omolola V. Akinola** & Adegoke J. (2020) Wildfire Policy Challenge in the United States: Implications for Wildfire Risk Reduction in Missouri. *Journal of Sustainable Development* 13(3).
2. **Omolola V. Akinola**, Adegoke J. & Ologunorisa T. E. (2019). Assessment of Social Vulnerability to Wildfire in Missouri, United States of America. *Journal of Sustainable Development.* 12. 76. 10.5539/jsd.v12n4p76.
3. **Omolola V. Akinola**, & Adegoke J. (2018). Assessment of forest fire vulnerability zones in Missouri, United States of America. *International Journal of Sustainable Development & World Ecology*. 26. 1-7. 10.1080/13504509.2018.1551815.

4. **Omolola V. Akinola** & Akindele S. O. (2015). Geospatial Analysis of Effects of Land Cover Change on Vegetation Index of Shasha Forest Reserve, Osun State, Nigeria, *Journal of Applied Tropical Agriculture*, School of Agriculture and Agricultural Technology, Federal University of Technology, Akure, Ondo state, Nigeria.
5. **Omolola V. Akinola**, Boko G. J., & Adagbasa E. G. (2014) Assessment of Impacts of Land Use Land Cover Change on Land Surface Temperature of Osogbo and Environs, Osun State, *Nigeria Journal of Sustainable Environmental Management (JSEM)* 6, 50-56.

CHAPTER IN A PUBLISHED BOOK

1. Temi E. Ologunorisa and **Omolola V. Akinola** (2015). Climate Change and the future of human security in Nigeria. In Obasanjo, O; Mabogunje, A. L. and Okebukola, P. A. (Eds.) Towards a New Dawn in Nigeria Post 2015, Chap. 34. Abeokuta: Centre for Human Security. Pp 533-550.

CONFERENCE PRESENTATIONS IN PROCEEDINGS

1. **Omolola V. Akinola** & Adegoke J. (2020). Wildfire Policy Challenge in the United States: Implications for Wildfire Risk Reduction in Missouri, American Association of Geographers Annual meeting, Denver, Colarado, April 2020.
2. **Omolola V. Akinola** & Adegoke J. (2019). Wildfires and Climate Variability in the State of Missouri, American Association of Geographers Annual meeting, Washington DC, April 2019.
3. **Omolola V. Akinola** & Adegoke J., Assessment of forest fire vulnerability zones in Missouri, United States of America, 2019 Interdisciplinary Student Conference and Community of Scholars event organized by the Graduate Union Council and UMKC

School of Graduate Studies March 13 - 14, 2019, Student Union Room 401B, UMKC Volker Campus

4. **Omolola V. Akinola**, Adegoke J. & Ologunorisa T. E. (2018). Assessment of Social Vulnerability to Wildfire in Missouri, United States of America: Policy Implication for Wildfire Risk Reduction, American Association of Geographers Annual meeting, New Orleans, Louisiana, April 10 – 14, 2018.
5. **Omolola V. Akinola** and Adegoke J. (2017). Urban Forest Mapping and Microclimate Impact Assessment Using Hyperspectral and LIDAR Data Fusion, 2017 Interdisciplinary Student Conference and Community of Scholars event organized by the Graduate Union Council and UMKC School of Graduate Studies Feb 8 - 9, 2017, Student Union Room 401B, UMKC Volker Campus.
6. **Omolola V. Akinola** (2015). Impact of Land Use and Land Cover on Land Surface Temperature of Akure, Ondo State, Nigeria Humbolt-Kolleg Ogbomoso International Conference held in Ladoke Akintola University of Technology PMB 4000, Ogbomoso, Nigeria, Tagged: Harvesting Research Outcomes: A Practical Plan to Confirm Achievement of the MDGs 13th-16th January, 2015.
7. **Omolola V. Akinola** & Akindele S. O. (2012). Assessment of land use changes in Shasha Forest Reserve, Osun State, Nigeria using Geographic Information System Published in 6th Annual Agric conference held in Federal University of Technology, Akure, Ondo state, Nigeria, 7th -9th November 2012 pp 145-154.
8. **Omolola V. Akinola** & Akindele S. O. (2012). Prospects of Remote Sensing and Geographic Information System in the Conservation of Tropical Rainforest by

Published in Proceedings of 3rd Biennial national conference of the forests and forest products society, held in University of Ibadan, Nigeria 3rd - 6th April 2012, pp 46.

9. **Omolola V. Akinola** and Akindele S. O. (2011). Forest Resources Management Role in Millennium Development Goals. Published in 34th Annual conference of the Forestry association of Nigeria, held in Osogbo, Osun state, Nigeria, 05th-10th December 2011, vol2, pp 523-537.